

# CASE FILE COPY

RESEARCH PROGRAM TO DEVELOP ALLOYS

FOR UP TO 1200°F STRAIN GAGES

BY

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## I. INTRODUCTION

Our rapidly expanding technology has brought forth numerous systems which perform in high-temperature environments. It is necessary to qualify materials for these systems and subsequently evaluate the performance of prototype and production units under operating conditions.

We must be concerned about the effects of temperature on the properties of these materials, especially when resulting changes might jeopardize specified performance of the materials in system components. Of primary concern is temperature dependence of mechanical, physical, metallurgical and electrical properties. The challenge in developing measuring devices and methods to evaluate high-temperature behavior arises from the fact that these devices are themselves subject to the same effects.

In 1957 when the temperature compensation of electric resistance strain gages was first introduced in practical terms, structural evaluation at other than ambient or low temperature conditions became more simple and accurate by an order of magnitude. It became possible to measure static strains accurately up to 600°F, even in the presence of thermal gradients. Soon, however, the development of high

energy power systems and the resulting advent of space exploration placed even greater demands upon measuring devices. One of the most serious needs was for a strain gage which could be used reliably for static measurements above 1000°F. This need has persisted to the present time in the face of considerable development effort which has yielded only partial solutions to the problem.

The essential requirements for a resistance strain gage alloy suitable for the measurement of steady state strains at 1200°F are:

1. Metallurgical stability at elevated temperature
2. A specific resistance of at least 200 Ohms/CMF
3. An apparent strain with temperature no larger than the applied or mechanical strain
4. Constant (or linear) temperature coefficient of resistance
5. Only moderate change in gage factor with temperature
6. Coefficient of expansion (PPM/°F) compatible with high-temperature structural materials
7. Only moderate change in gage factor with strain
8. Adequate mechanical strength

In order to meet the above requirements, "building blocks" were selected for the design of strain gage alloys (Table I). The investigation reported herein does not exhaust the possibilities for new alloys from this group.



Table I

## Elements for Design of Strain Gage Filaments

Element	Atomic Number	Melting Point °F	Resistivity $\Omega/\text{CMF}$	Temperature Coefficient $\mu\Omega/\Omega/^\circ\text{F}$	Thermal Expansion $\mu\epsilon/^\circ\text{F}$	Modulus of Elasticity $10^6 \text{ lb/in}^2$	Oxidation Temperature °F
Al	13	1220	16	2400	12.9	10	400
Ti	22	3270	300	3000	4.8	15	500
Cr	24	3350	78	1700	4.0	36	800
Mn	25	2268	260	110-180	12.7	23	70
Fe	26	2795	60	3400	6.4	29	600
Co	27	2715	38	3700	6.8	30	575
Ni	28	2650	50	2700	7.3	30	1100
Cu	29	1981	11	2200	9.2	16	600
Mo	42	4750	30	1800	2.7	50	400
Pd	46	2830	60	1800	6.4	17	1300
W	74	6120	33	2500	2.4	53	300
Pt	78	3224	59	1700	4.9	24	2200

## II. OBJECTIVES

The present research and development program was undertaken with a threefold purpose:

1. Develop satisfactory alloys for temperature compensated strain gages for the measurement of steady-state strains up to 1200°F.
2. Critically evaluate these alloys in actual strain gage configurations, taking into consideration necessary refinements in the entire measuring system, e.g., adhesives, lead-in wiring, protective coatings, instrumentation, etc.
3. Produce sufficient quantities of these alloys and associated materials to permit fabrication of initial production quantities of gage systems.

### III. PROCEDURE

In pursuing the objectives of this investigation, fifteen alloys were melted and wire samples drawn, having diameters of 0.005", 0.002", 0.001". One alloy was reduced to foil having a thickness of 0.0004" and 0.0002".

Pertinent strain gage properties of each of these alloys were determined for various conditions of heat treatment. Three nickel-base "Superalloys" were tested (Table II). The iron-base "Superalloy" evaluated is listed in Table III. A cobalt-base "Superalloy" also was tested (Table IV). Numerous precious-metal alloys of platinum were selected for evaluation (Tables V, VI, and VII).

The alloys selected were vacuum melted and samples were reduced to fine wire and foil by qualified sources. The evaluation of the alloys was conducted at the Detroit facility of William T. Bean, Inc. (Figures 1 and 2) Strain gages were fabricated from each alloy (Figures 2 and 3) and mounted on test specimens (Figure 4).

An improved ceramic cement (H-1) was used as the bonding agent. Nichrome ribbons were used to connect the strain gage filament to lead-in wires. All connections were spot-welded. Stainless steel-clad copper wires with fiberglass insulation were used in the conventional 3-wire

circuit. The completed installation was coated with a white protective coating (Gagekote # 1) in order to reduce radiation effects at elevated temperature. The test specimen was wrapped in several layers of thin fiberglass cloth in order to assure uniform heating and cooling.

Test results are summarized in Tables II through VI. Significant characteristics are graphically presented in this report by the extensive use of an X-Y Recorder, for example, the Resistance vs. Temperature Curves shown in Figure 5.

The E.M.F. of a chromel/alumel thermocouple was used to drive the X-Axis of the Moseley Recorder. The thermocouple output was simultaneously monitored by a Doric DVM.

Table II

Nickel-Base Alloys

No.	Alloy	$\Omega/\text{CMF}$ @ 100°F	Gage Factor	% $\Delta R$ @ 1100°F	% $\Delta R/100^\circ\text{F}$	$\mu\Omega/\Omega/^\circ\text{F}$	Apparent $\mu\epsilon/^\circ\text{F}$	Notes
16	Nichrome V 80 Ni 20 Cr	650	2.1	4.0	0.4	40	19	Not stable
7	Inconel 102 67 Ni 15 Cr 8 Fe 3 Mo 3 W 3 Cd	662-771	2.2	3.2-3.6	0.32-0.36	32-36	15-16	Not stable
8	Hastelloy N 67 Ni 17 Mo 7 Cr 5 Fe	606-755	2.3	4.0	0.4	40	17	Not stable
5	Rene 41 54 Ni 19 Cr 11 Co 10 Mo 3 Ti	710-816	2.3	1.5-4.5	0.15-0.45	15-45	7-20	Not stable

Table III

Iron-Base Alloy

No.	Alloy	$\Omega/\text{CMF}$ @ 100°F	Gage Factor	% $\Delta R$ @ 1100°F	% $\Delta R/100^\circ\text{F}$	$\mu\Omega/\Omega/^\circ\text{F}$	Apparent $\mu\epsilon/^\circ\text{F}$	Notes
9	N-155	591-625	2.4	20.5	2.05	205	85	Not stable
	30 Fe							
	21 Cr							
	20 Ni							
	20 Co							

Table IV

Cobalt-Base Alloy

No.	Alloy	$\Omega/\text{CMF}$ @ 100°F	Gage Factor	% $\Delta R$ @ 1100°F	% $\Delta R/100^\circ\text{F}$	$\mu\Omega/\Omega/^\circ\text{F}$	Apparent $\mu\epsilon/^\circ\text{F}$	Notes
6	S-816	555-610	2.0	13.5-15.5	1.35-1.55	135-155	65-75	Not stable
	44 Co							
	20 Ni							
	20 Cr							
	4 Mo							
	4 W							
	3 Fe							

Table V

Alloys of Platinum-Copper

No.	Alloy	$\Omega/\text{CMF}$ @ 100°F	Gage Factor	% $\Delta R$ @ 1100°F	% $\Delta R/100^\circ\text{F}$	$\mu\Omega/\Omega/^\circ\text{F}$	Apparent $\mu\epsilon/^\circ\text{F}$	Notes
1	80 Pt 20 Cu	220-340	2.0	25	2.5	250	125	Not stable
15	80 Pt 15 Cu 5 Ni	440-444	2.1	15	1.5	150	71	Some instability above 1000°F
10	80 Pt 15 Cu 5 W	Not workable		5	.5	50	----	Not stable
2	90 Pt 8 Cu 2 W	320-344	2.4	20	2.0	200	83	Some instability above 1000°F
12	90 Pt 5 Cu 5 W	Not workable		22	2.2	220	----	Unstable above 1000°F



Table VI

Alloys of Platinum-Nickel

No.	Alloy	$\Omega/\text{CMF}$ @ 100°F	Gage Factor	% $\Delta R$ @ 1100°F	% $\Delta R/100^\circ\text{F}$	$\mu\Omega/\Omega/^\circ\text{F}$	Apparent $\mu\epsilon/^\circ\text{F}$	Notes
14	90 Pt 10 Ni	192	4.2	63	6.3	630	150	Good stability to 1400°F
3	90 Pt 8 Ni 2 W	188	4.2	68	6.8	680	162	Good stability to 1400°F
4	90 Pt 8 Ni 2 Cr	228	4.1	44	4.4	440	107	Good stability to 1400°F
11	90 Pt 5 Ni 5 Cr	Not workable		170	17.0	1700	---	Erratic above 700°F
15	80 Pt 5 Ni 15 Cu	440-476	2.1	15	1.5	150	71	Unstable above 1000°F

Table VII

Alloys of Platinum-Tungsten

No.	Alloy	$\Omega/\text{CMF}$ @ 100°F	Gage Factor	% $\Delta R$ @ 1100°F	% $\Delta R/100^\circ\text{F}$	$\mu\Omega/\Omega/^\circ\text{F}$	Apparent $\mu\epsilon/^\circ\text{F}$	Notes
13	92 Pt 8 W	330-355	5.3	21	2.1	210	40	Good stability to 1400°F
2	90 Pt 2 W 8 Cu	320-344	2.4	20	2.0	200	83	Not stable above 1000°F
3	90 Pt 2 W 8 Ni	188-210	4.2	68	6.8	680	162	Good stability to 1400°F

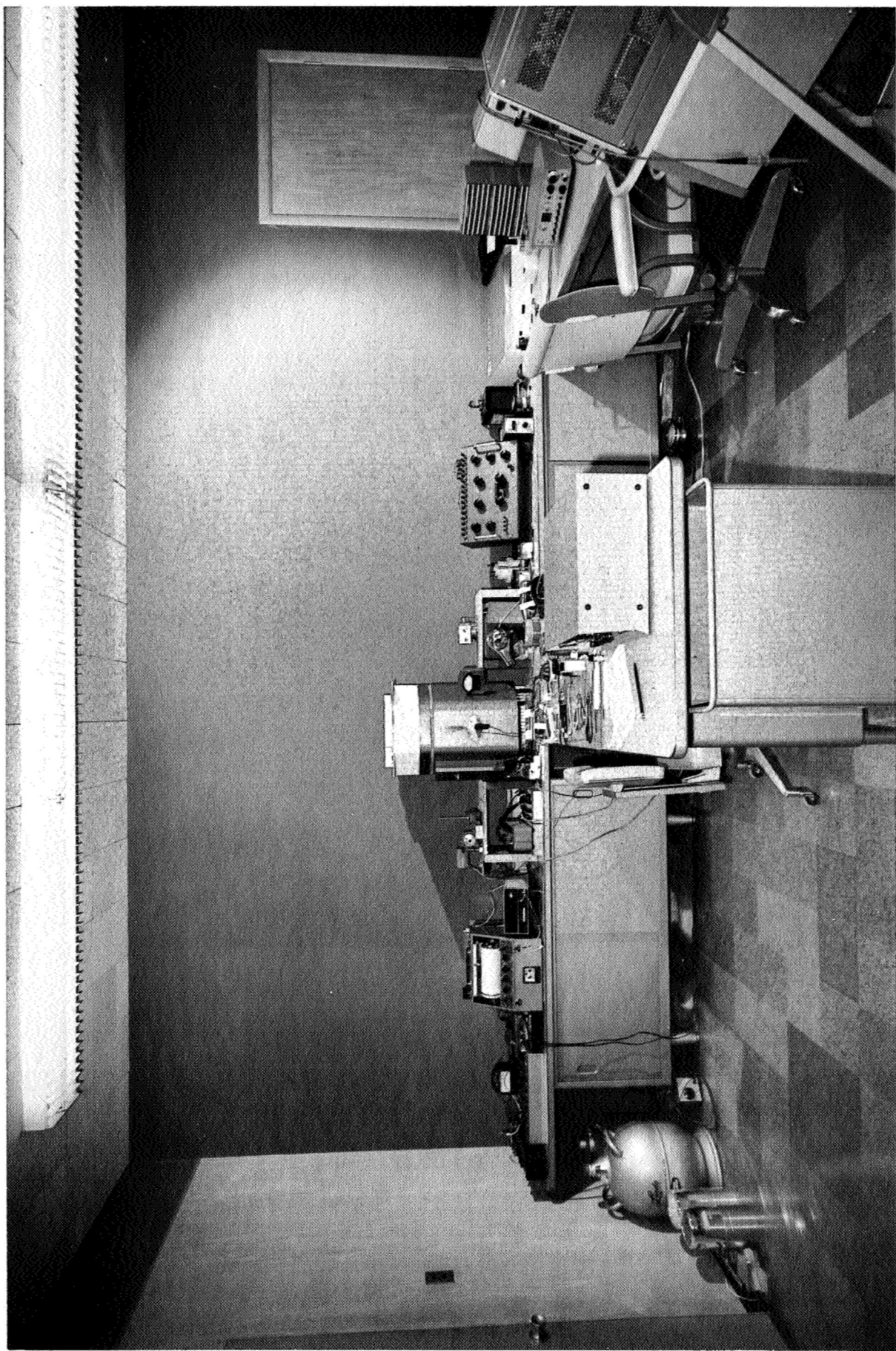


FIGURE 1. STRAIN GAGE EVALUATION LABORATORY

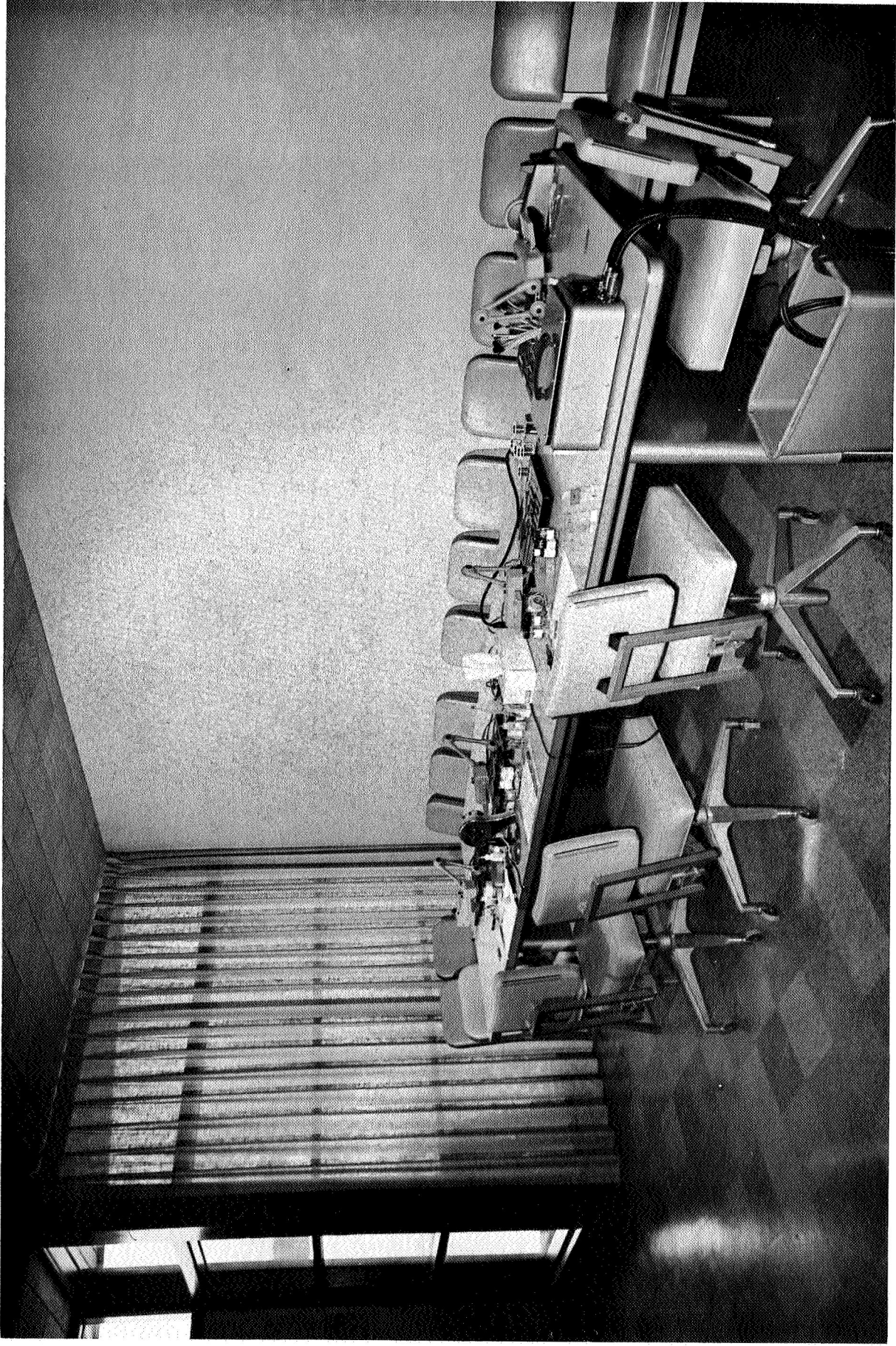
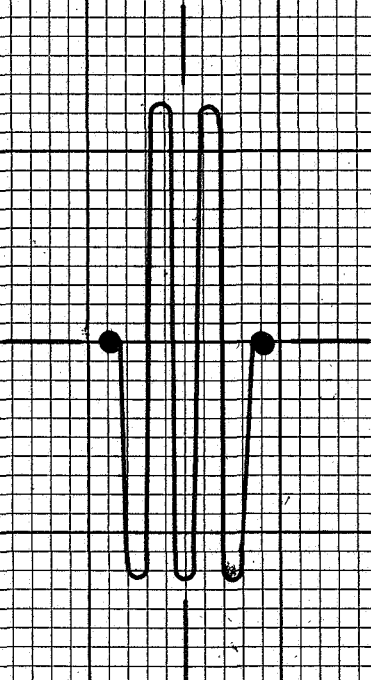


FIGURE 2. STRAIN GAGE FABRICATION & INSTALLATION AREA



GRID LAYOUT

USED FOR EVALUATION OF STRAIN GAGE ALLOYS  
(2-3/8" GAGE LENGTH--12" FILAMENT LENGTH)



FULL SIZE

LOAD TEST MATERIAL BEAN

FIGURE 3.

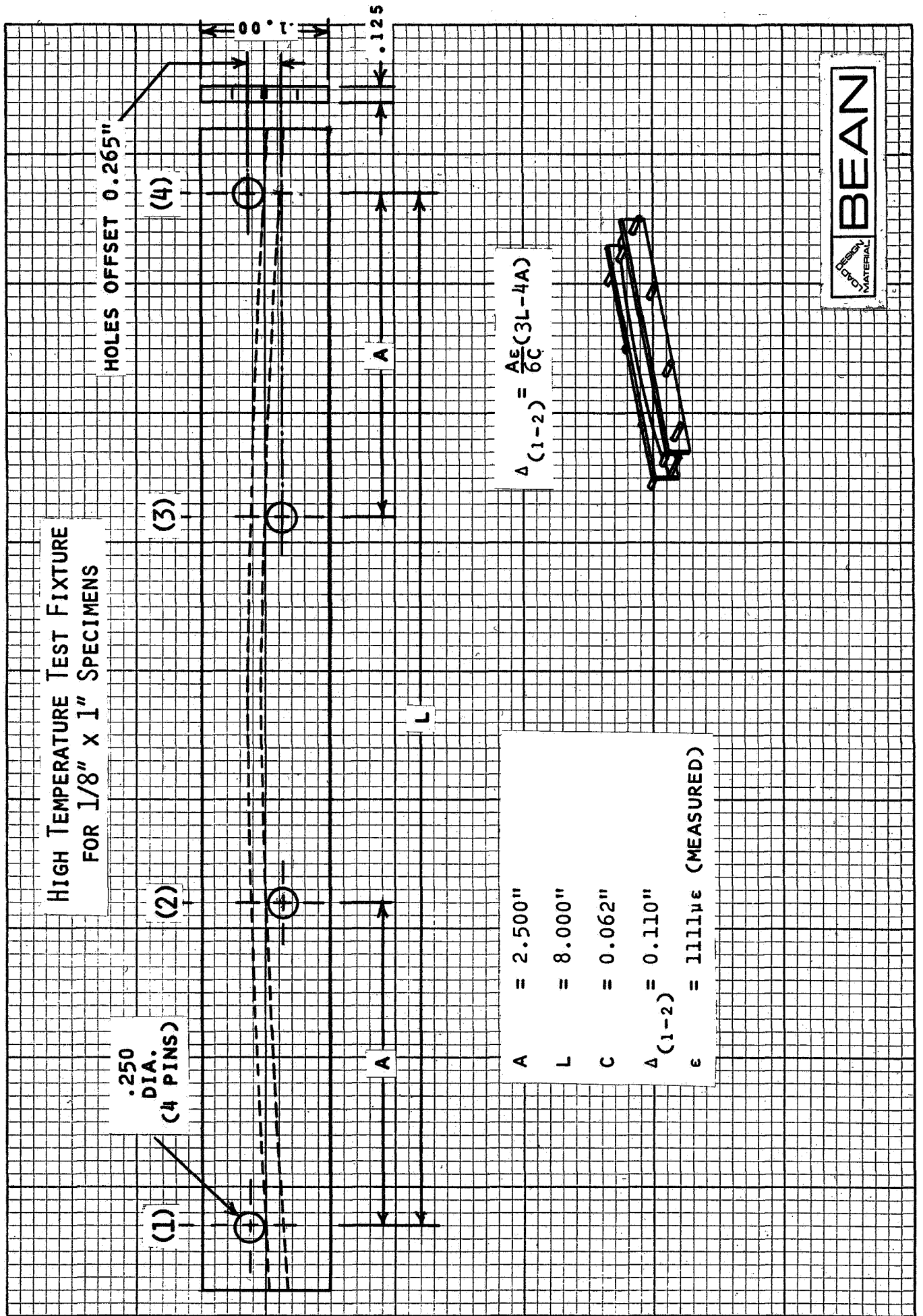
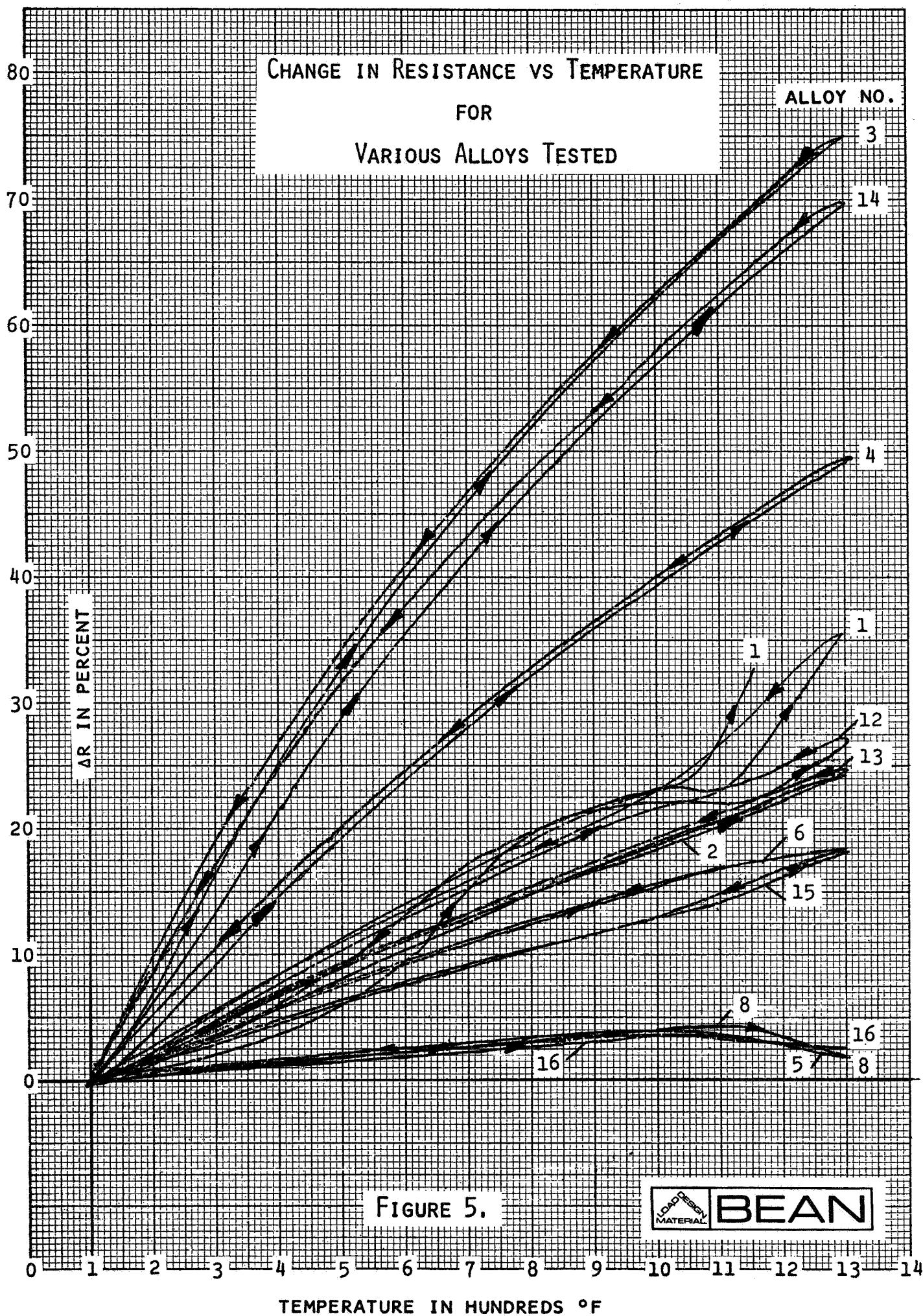


FIGURE 4.



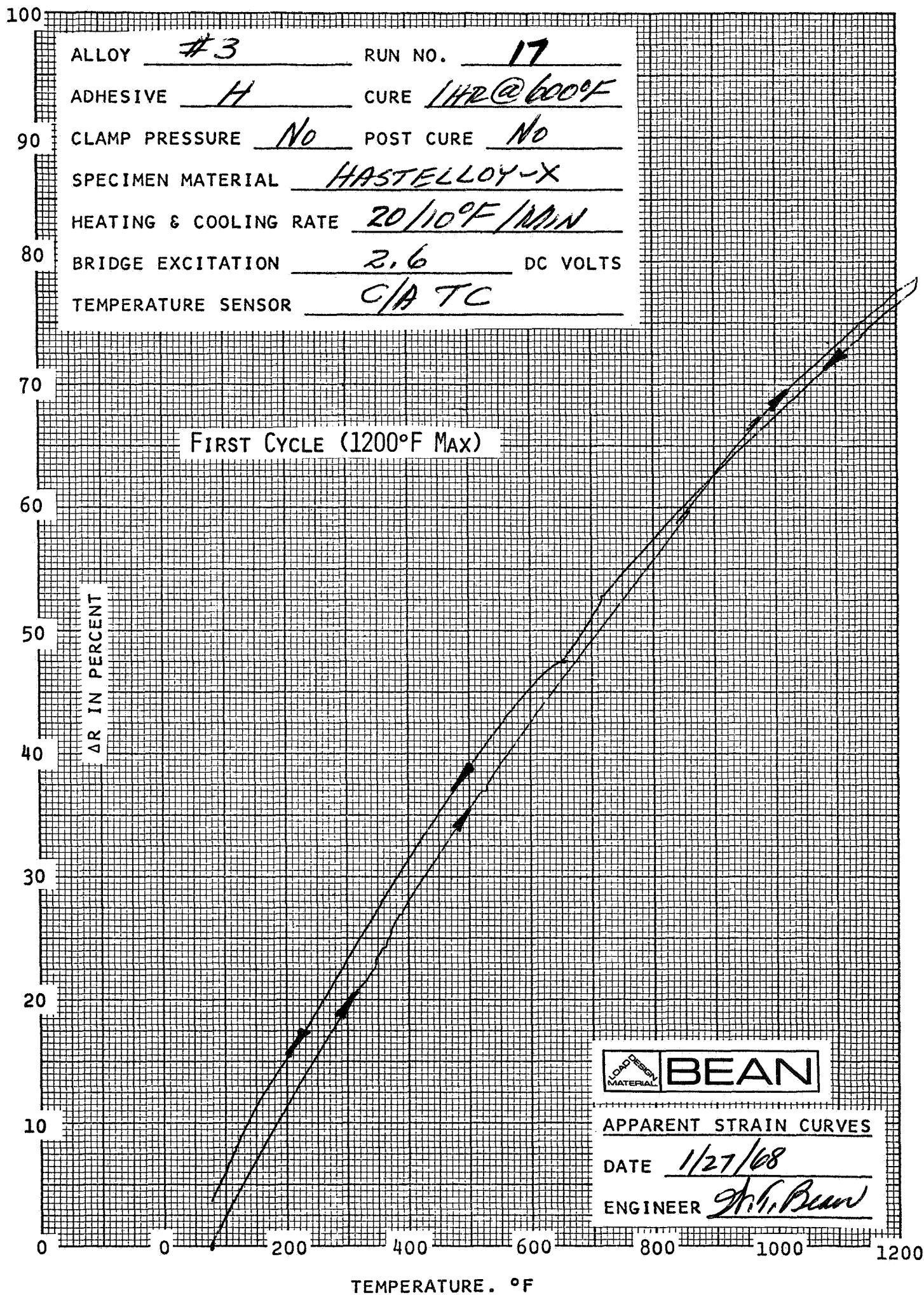
#### IV. GRAPHICAL RESULTS

Of all the strain gage materials tested, only three alloys of platinum exhibited satisfactory stability up to 1200°F. Curves showing the first and second heat cycles to 1200°F for these alloys follow (Runs # 17, # 18, # 20, # 21, # 100, # 101). Typical Resistance/Temperature/Time Curves on a high strength nickel-base alloy are shown (Runs # 23, # 27, # 29, # 62, # 160, # 161, # 163 through # 167). Figure 6 combines Runs # 60 and # 61 and indicates the apparent strain from -320°F to +950°F.

Test results on the other alloys follow:

<u>Alloy No.</u>	<u>Run No.</u>
1	9, 10
2	13, 14, 15
5	24, 60
6	84, 85
7	88, 89
8	91, 92
9	94, 95
10	97
11	102, 104
14	107
15	109





100  
ALLOY #3 RUN NO. 18  
ADHESIVE H CURE 1HR@600°F  
90 CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
80 BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/ATC

70

SECOND CYCLE (1200°F MAX)

60

ΔR IN PERCENT

50

40

30

20

10

0

0

200

400

600

800

1000

1200

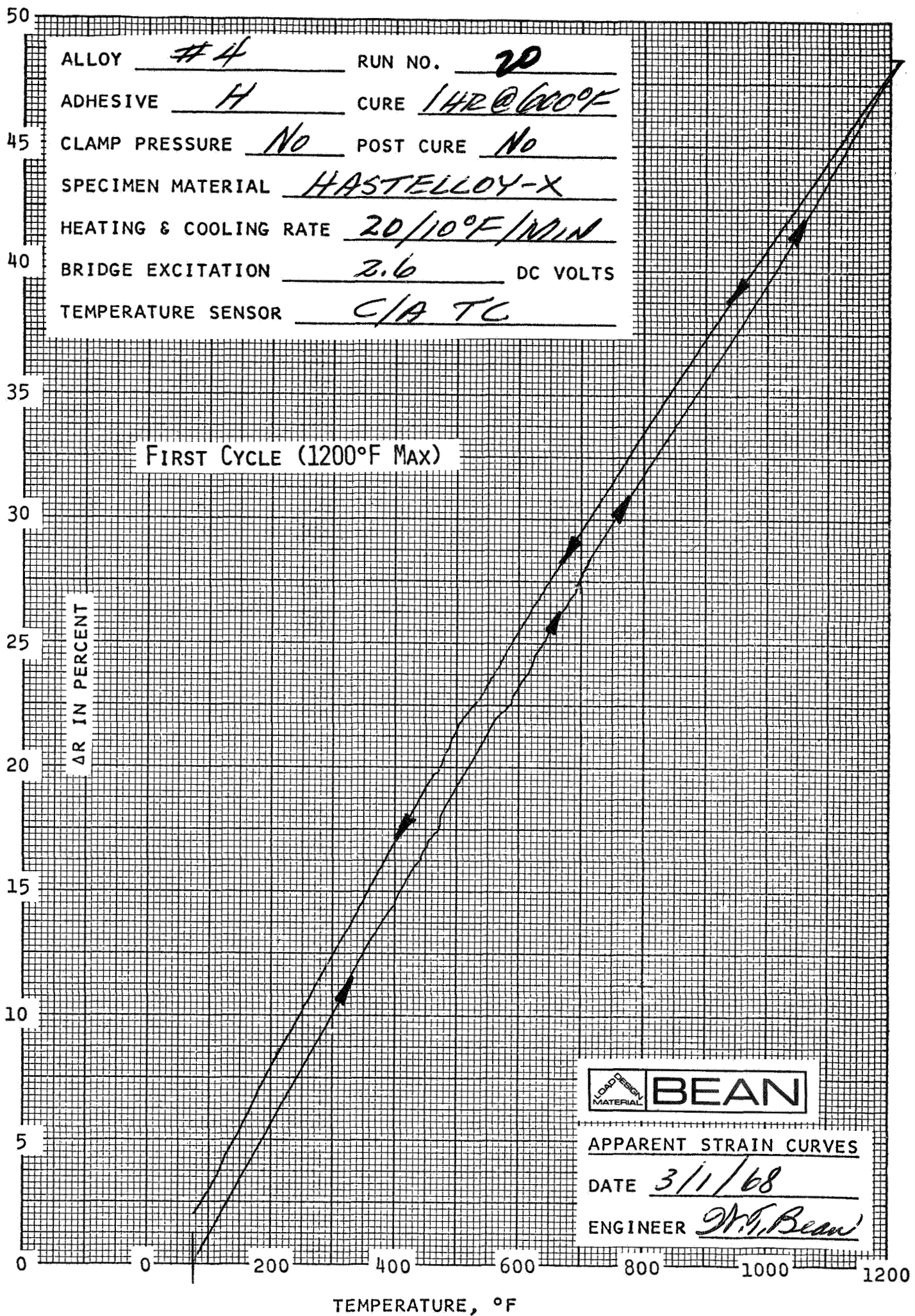
TEMPERATURE, °F



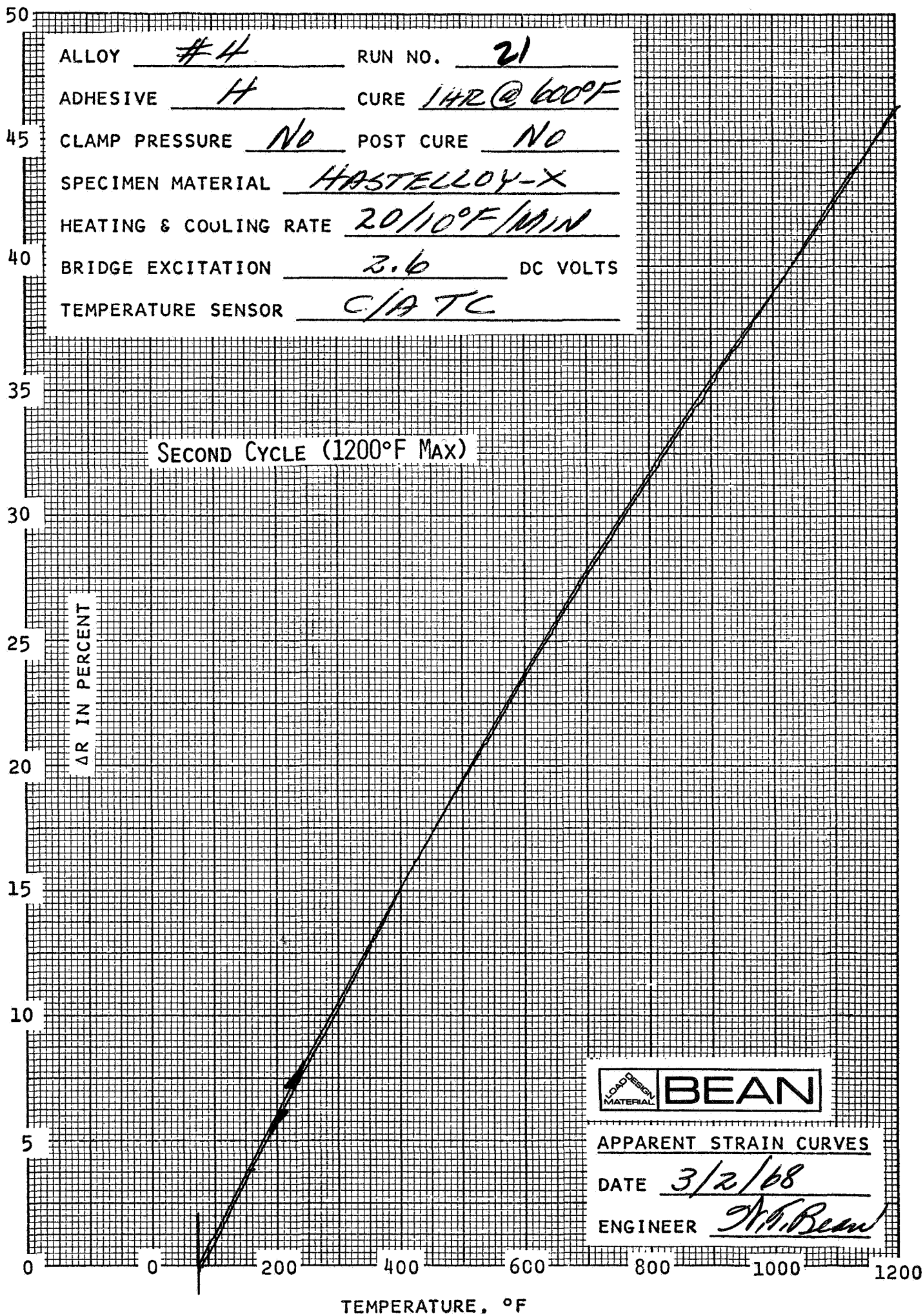
APPARENT STRAIN CURVES

DATE 1/28/68

ENGINEER W.H. Bean



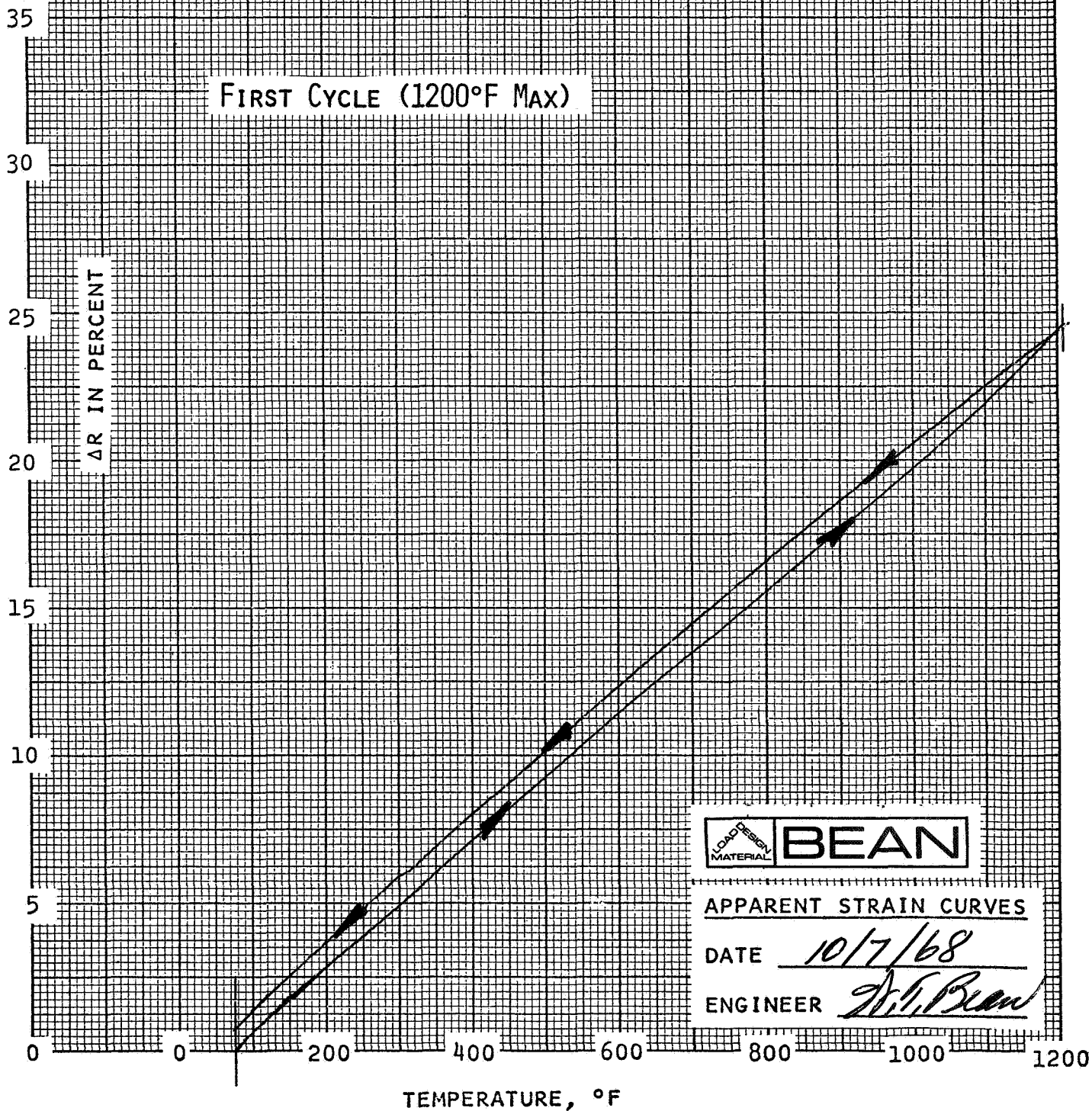




ALLOY #13 RUN NO. 100  
ADHESIVE H CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC

FIRST CYCLE (1200°F MAX)

ΔR IN PERCENT



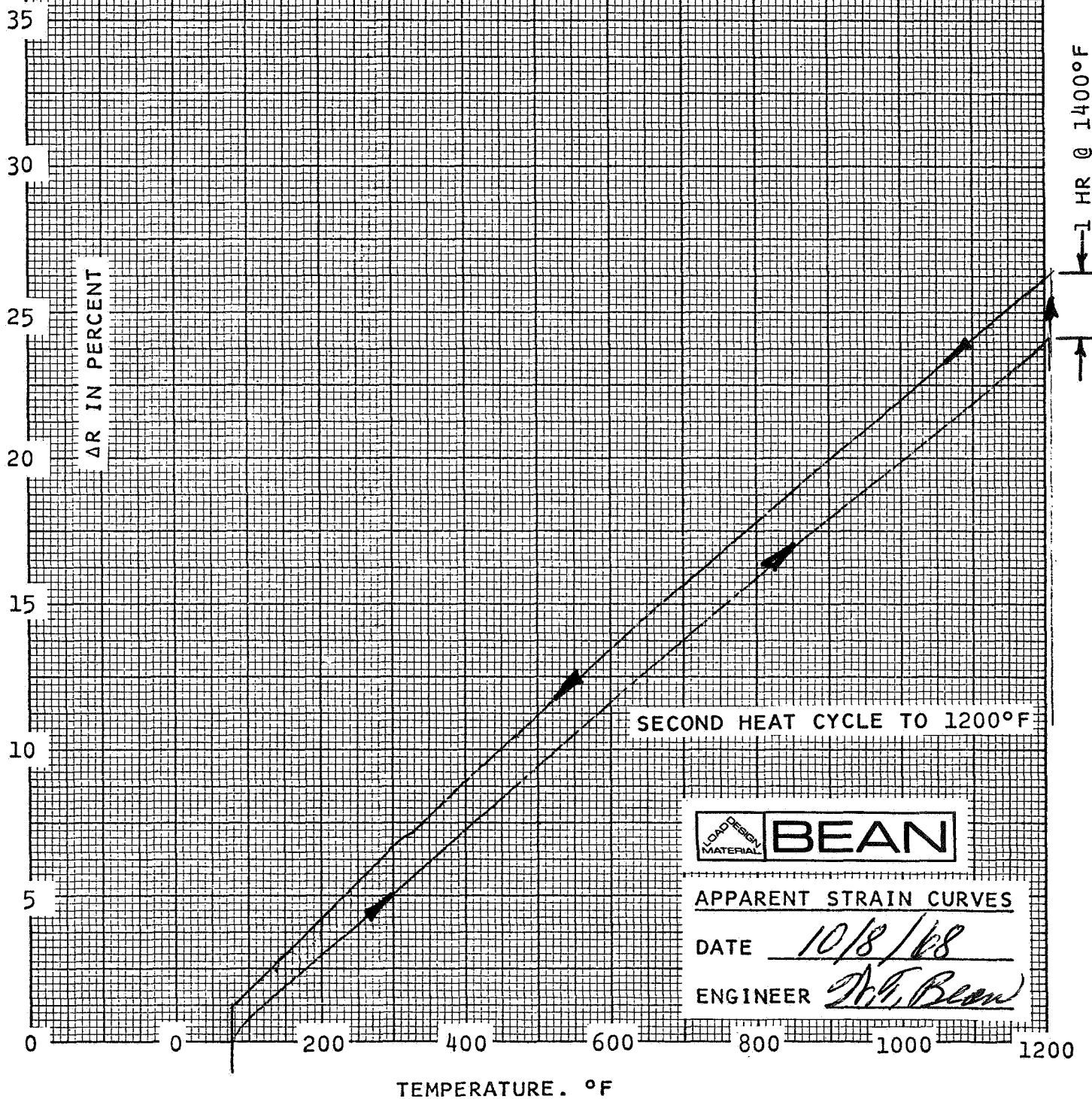
LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 10/7/68

ENGINEER J. H. Bean

ALLOY #13 RUN NO. 101  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC



20

ALLOY #5 (FOIL) RUN NO. 23ADHESIVE H CURE 1HR @ 600°F

18

CLAMP PRESSURE No POST CURE NoSPECIMEN MATERIAL HASTELLOY-XHEATING & COOLING RATE 20/20°F/MIN

16

BRIDGE EXCITATION 2.6 DC VOLTSTEMPERATURE SENSOR C/A - TC

14

FIFTH (1100°F MAX)

12

FOURTH HEAT CYCLE (1050°F MAX)

10

THIRD HEAT CYCLE (1000°F MAX)

8

SECOND HEAT CYCLE (950°F MAX)

6

FIRST HEAT CYCLE (900°F MAX)

4

2

0

ΔR IN PERCENT

0

200

400

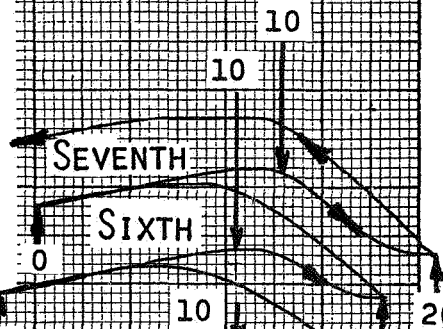
600

800

1000

1200

TEMPERATURE, °F

LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 4/1/68ENGINEER W. F. Bean



+5

ALLOY #5 RUN NO. 27ADHESIVE H CURE 1HR @ 600°F+4 CLAMP PRESSURE No POST CURE NoSPECIMEN MATERIAL HASTELLOY-XHEATING & COOLING RATE 20/10°F/MIN+3 BRIDGE EXCITATION 2.6 DC VOLTSTEMPERATURE SENSOR C/A TC

+2

SECOND CYCLE (1200°F MAX)

+1

ΔR IN PERCENT

0

-1

-2

-3

-4

-5

0

30

40

50

57

MINUTES



APPARENT STRAIN CURVES

DATE 4/25/68ENGINEER H.T. Bean

-5

0

200

400

600

800

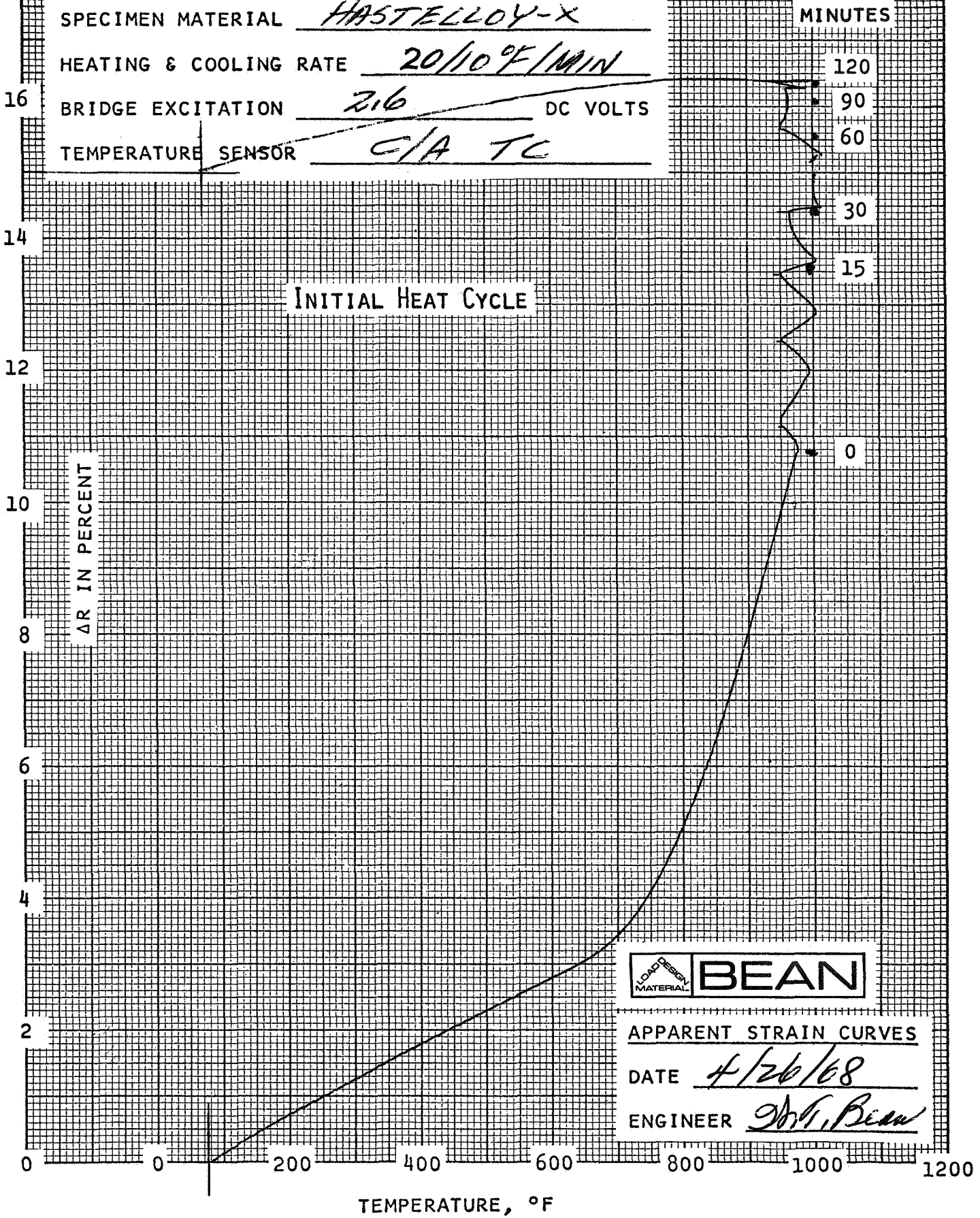
1000

1200

TEMPERATURE, °F



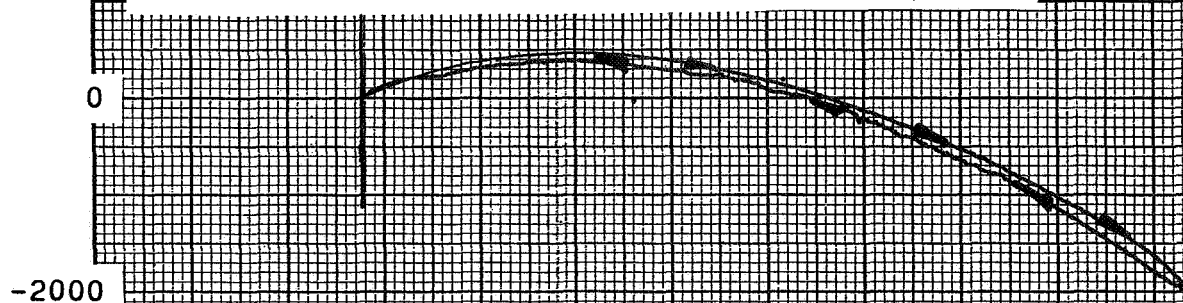
ALLOY #5 RUN NO. 29  
ADHESIVE H CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 216 DC VOLTS  
TEMPERATURE SENSOR C/A TC



LOADING DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES  
DATE 4/26/68  
ENGINEER W.H. Bean

ALLOY #5 RUN NO. 62  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC



STABILIZED FOR 950°F MAX

MICROSTRAIN



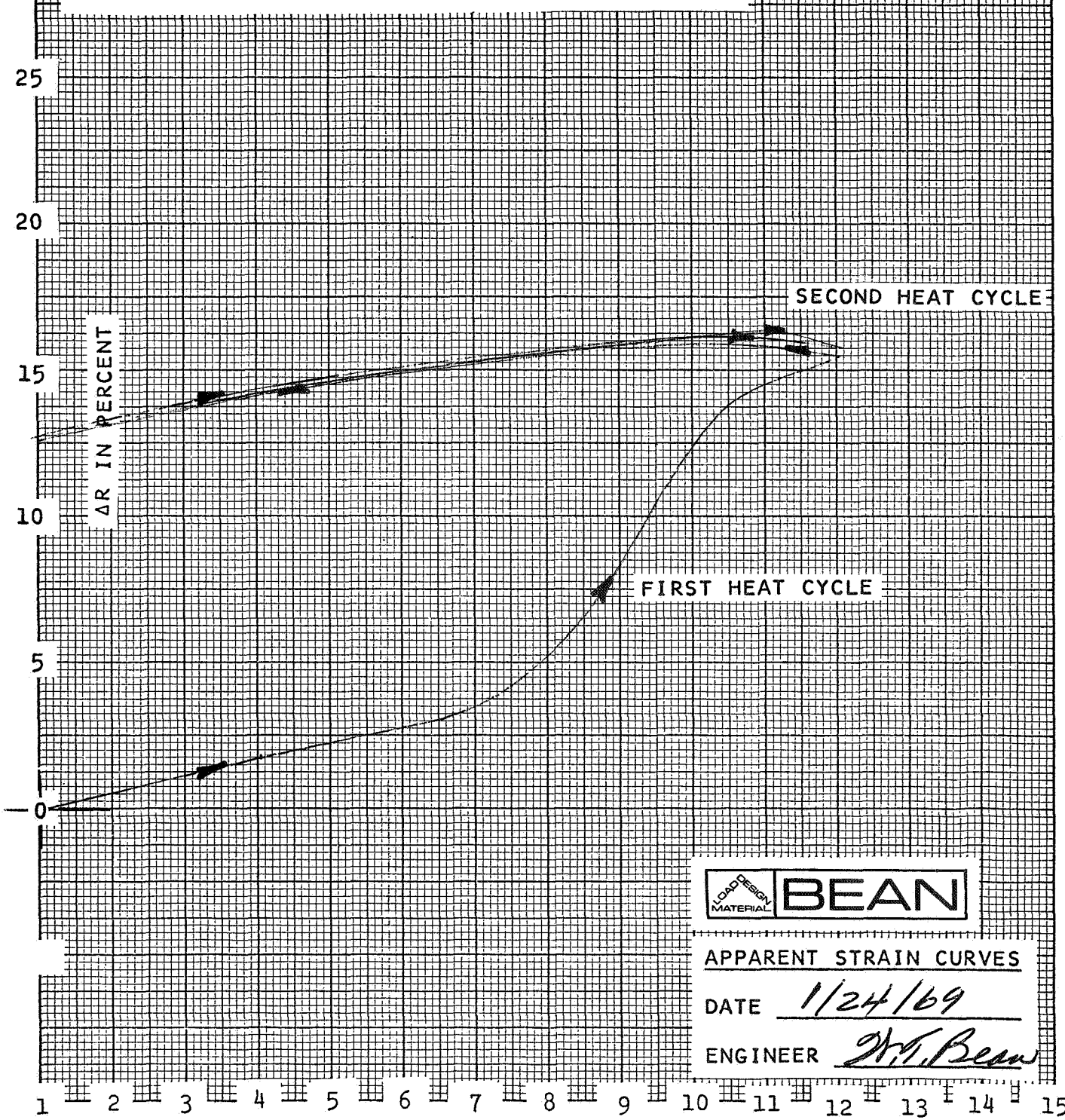
APPARENT STRAIN CURVES

DATE 6/21/68

ENGINEER W.F. Bean

TEMPERATURE, °F

ALLOY #5 (FOIL) RUN NO. 160  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC



LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 1/24/69

ENGINEER H.T. Bean

TEMPERATURE IN HUNDREDS °F

ALLOY #5 (FOIL) RUN NO. 161  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

THIRD HEAT CYCLE TO 1200°F

ΔR IN PERCENT

LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 1/24/69

ENGINEER W. L. Bean

TEMPERATURE IN HUNDREDS °F



ALLOY # 5 (FOIL) RUN NO. 163  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

6

5

4

3

2

1

0

ΔR IN PERCENT

HEAT CYCLE AFTER 1 HR @ 1250°F

LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 1/25/69

ENGINEER W. F. Bean

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

TEMPERATURE IN HUNDREDS °F

18

ALLOY #5 (FOIL) RUN NO. 164ADHESIVE H CURE 1 HR @ 600°F

16

CLAMP PRESSURE No POST CURE NoSPECIMEN MATERIAL HASTELLOY-XHEATING & COOLING RATE 20/10°F/MIN

14

BRIDGE EXCITATION 6.4 DC VOLTSTEMPERATURE SENSOR C/A TC

12

HEAT CYCLE TO 1400°F

10

 $\Delta R$  IN PERCENT

8

6

4

AFTER 1 HR @ 1250°F

PLUS 1 HR @ 1400°F

2

0

1 HR

LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 1/25/69ENGINEER J. F. Bean

1

2

3

4

5

6

7

8

9

10

11

12

13

14

15

TEMPERATURE IN HUNDREDS °F

18

ALLOY #5 (FOIL) RUN NO. 165ADHESIVE H CURE 1 HR @ 600°F

16

CLAMP PRESSURE NO POST CURE NOSPECIMEN MATERIAL HASTELLOY-XHEATING & COOLING RATE 20/10°F/MIN

14

BRIDGE EXCITATION 6.4 DC VOLTSTEMPERATURE SENSOR C/A TC

12

10

 $\Delta R$  IN PERCENT

PLUS 1 HR @ 1500°F

AFTER 1 HR @ 1250°F  
PLUS 1 HR @ 1400°F

8

6

4

2

0

1

2

3

4

5

6

7

8

9

10

11

12

13

14

15

TEMPERATURE IN HUNDREDS °F



BEAN

APPARENT STRAIN CURVES

DATE 1/25/69ENGINEER A. F. Bean



18

ALLOY #5 (FOIL) RUN NO. 166ADHESIVE H CURE 1 HR @ 600°F16 CLAMP PRESSURE No POST CURE NoSPECIMEN MATERIAL HASTELLOY-XHEATING & COOLING RATE 20/10°F/MIN14 BRIDGE EXCITATION 6.4 DC VOLTSTEMPERATURE SENSOR C/A TC

12

10

ΔR IN PERCENT

8

4

2

0

HEAT CYCLE TO 1500°F

AFTER 1 HR @ 1250°F  
PLUS 1 HR @ 1400°F  
PLUS 1 HR @ 1500°F

PLUS 1 HR @ 1600°F

(1 HR @ 1600°F)

LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 1/27/69ENGINEER W. F. Bean

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

TEMPERATURE IN HUNDREDS °F



18  
16  
14  
12  
10  
8  
6  
4  
2  
0

ALLOY #5 (FOIL) RUN NO. 167  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

HEAT CYCLE TO 1500°F

AFTER 1 HR @ 1250°F  
PLUS 1 HR @ 1400°F  
PLUS 1 HR @ 1500°F  
PLUS 1 HR @ 1600°F

ΔR IN PERCENT



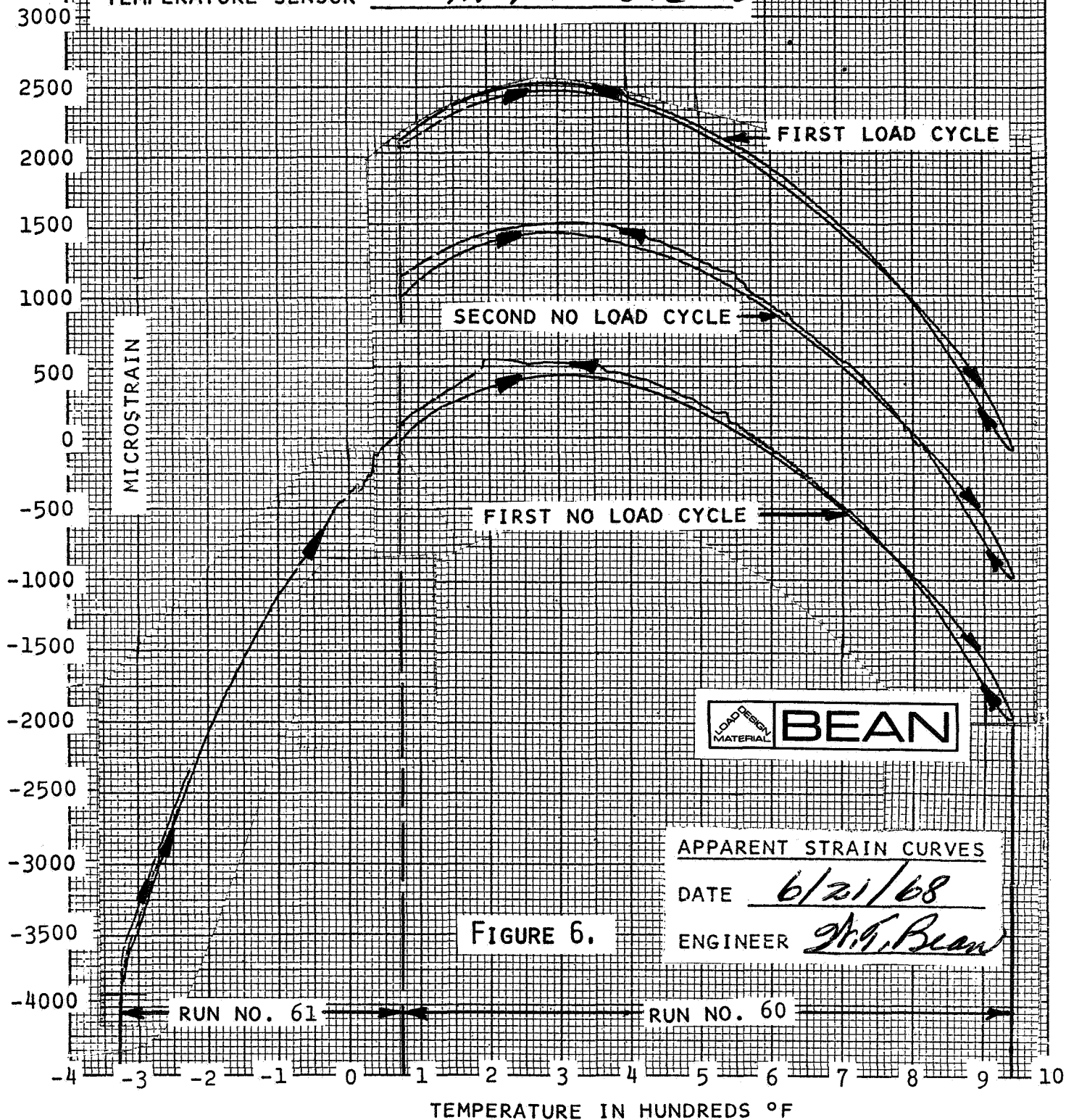
APPARENT STRAIN CURVES

DATE 1/27/69

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TEMPERATURE IN HUNDREDS °F

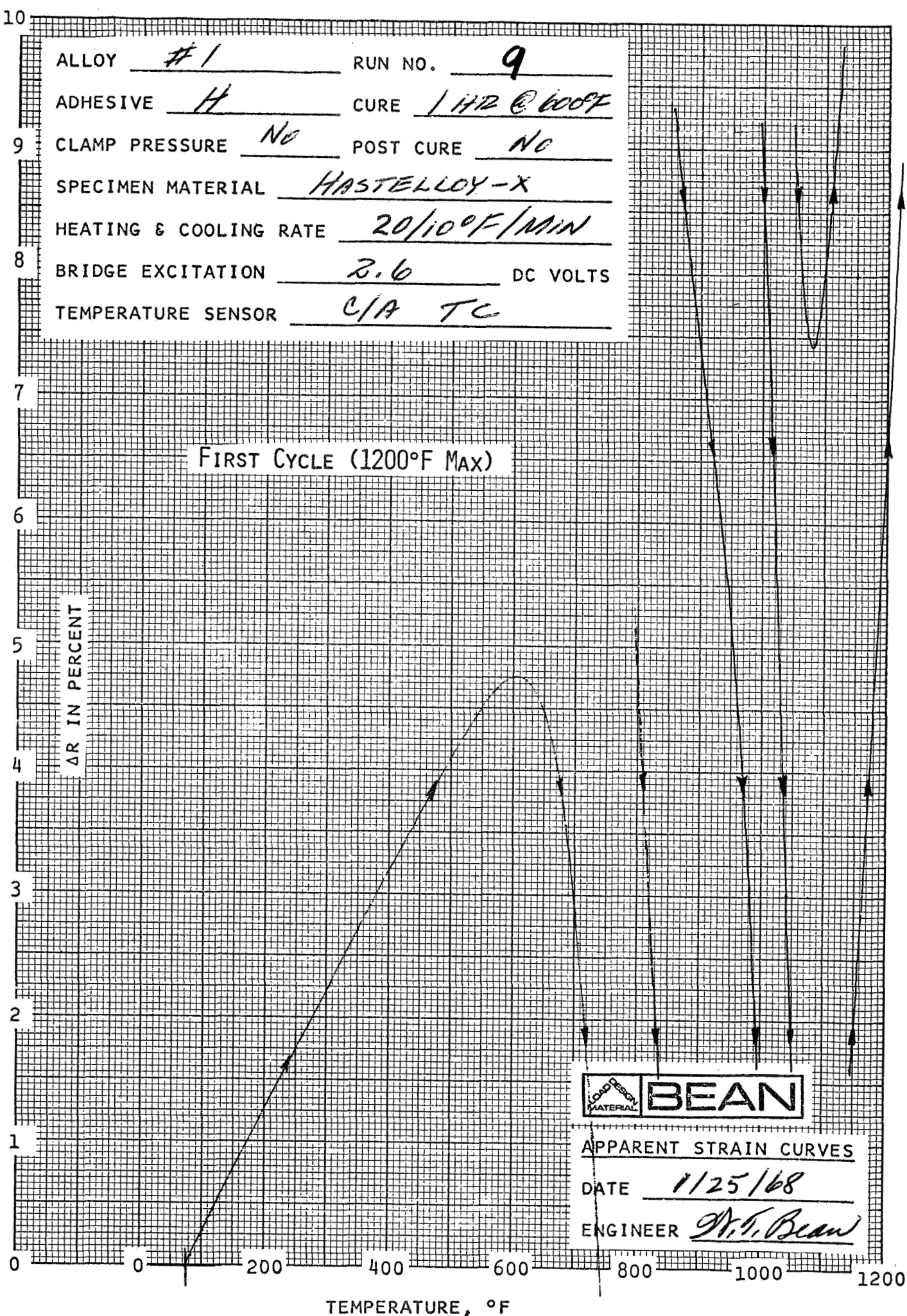
ALLOY #5 RUN NO. 60+61  
ADHESIVE H CURE 1HR@600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/ATC+STG-50



ALLOY #1 RUN NO. 9  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC

FIRST CYCLE (1200°F MAX)

ΔR IN PERCENT



LOADING MATERIAL **BEAN**

APPARENT STRAIN CURVES

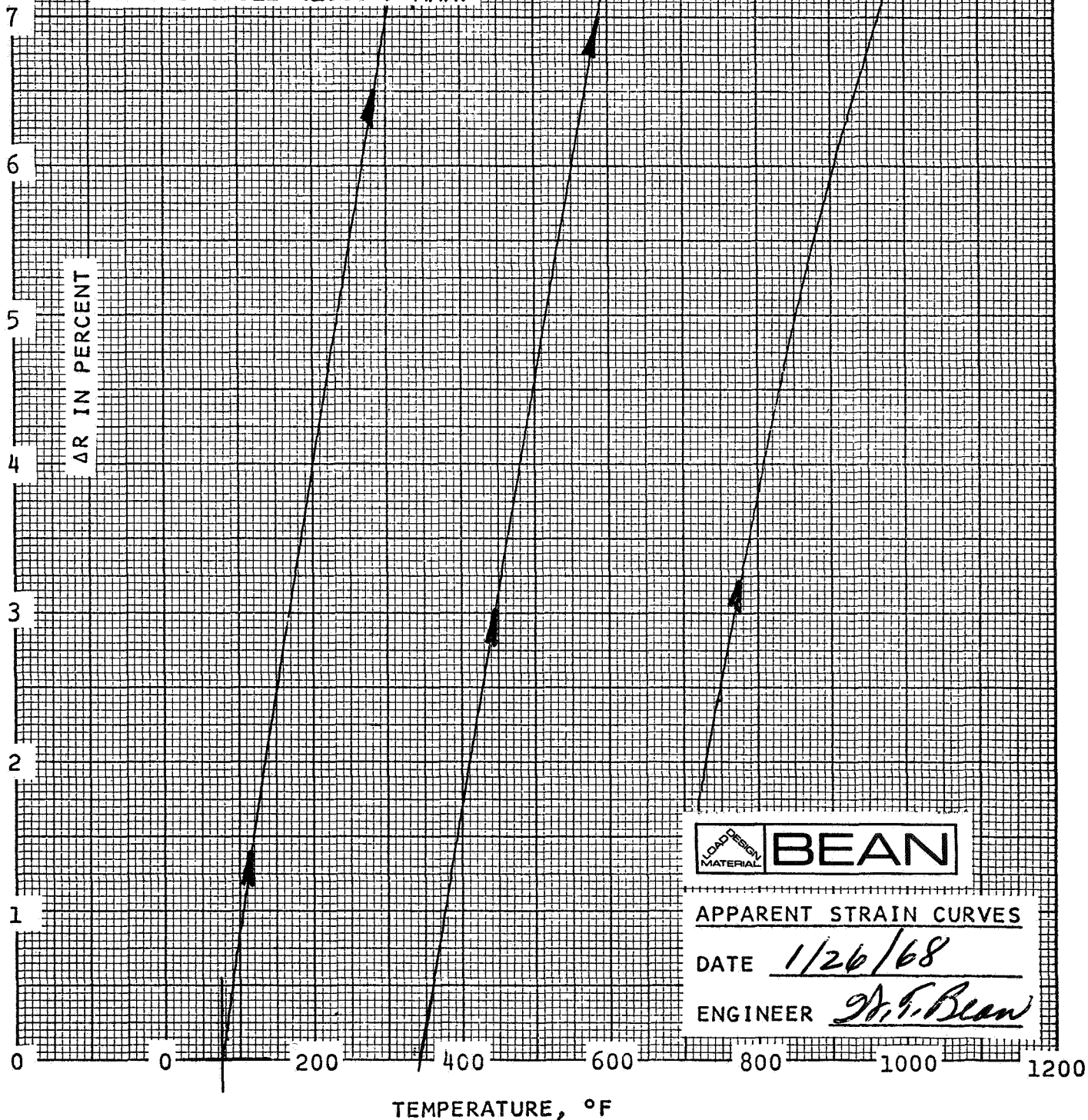
DATE 1/25/68

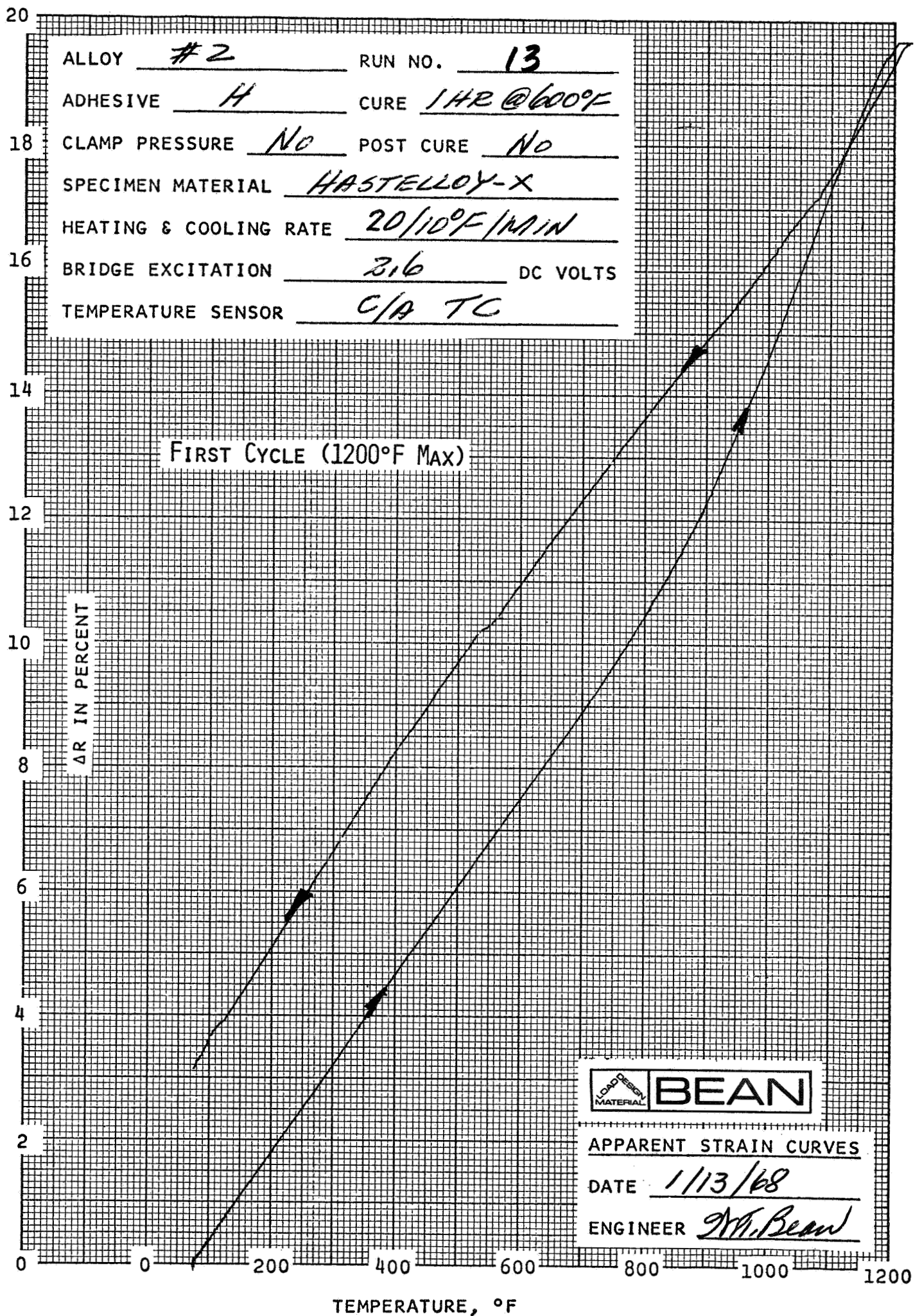
ENGINEER W. F. Bean



ALLOY #1 RUN NO. 10  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/100°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC

SECOND CYCLE (1000°F MAX)





20

ALLOY # 2 RUN NO. 14ADHESIVE H CURE 1 HR @ 600°F18 CLAMP PRESSURE No POST CURE NoSPECIMEN MATERIAL HASTELLOY-XHEATING & COOLING RATE 20/10°F/MIN16 BRIDGE EXCITATION 3.6 DC VOLTSTEMPERATURE SENSOR C/A TC

14

SECOND CYCLE (1200°F MAX)

12

10

8

6

4

2

ΔR IN PERCENT

0

0

200

400

600

800

1000

1200

TEMPERATURE, °F

LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 1/14/68ENGINEER J.H. Bean



20

ALLOY #2 RUN NO. 15  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC

18

16

14

12

10

8

6

4

2

0

ΔR IN PERCENT

FIRST HEAT CYCLE TO 1425°F



BEAN

APPARENT STRAIN CURVES

DATE 1/15/68

ENGINEER W. T. Bean

0

0

200

400

600

800

1000

1200

TEMPERATURE, °F

8

ALLOY #5 (FOIL) RUN NO. 24  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC

7

6

5

4

3

2

1

0

-1

0

ΔR IN PERCENT

EIGHTH HEAT CYCLE

NINTH HEAT CYCLE

TENTH HEAT CYCLE



BEAN

APPARENT STRAIN CURVES

DATE 4/3/68

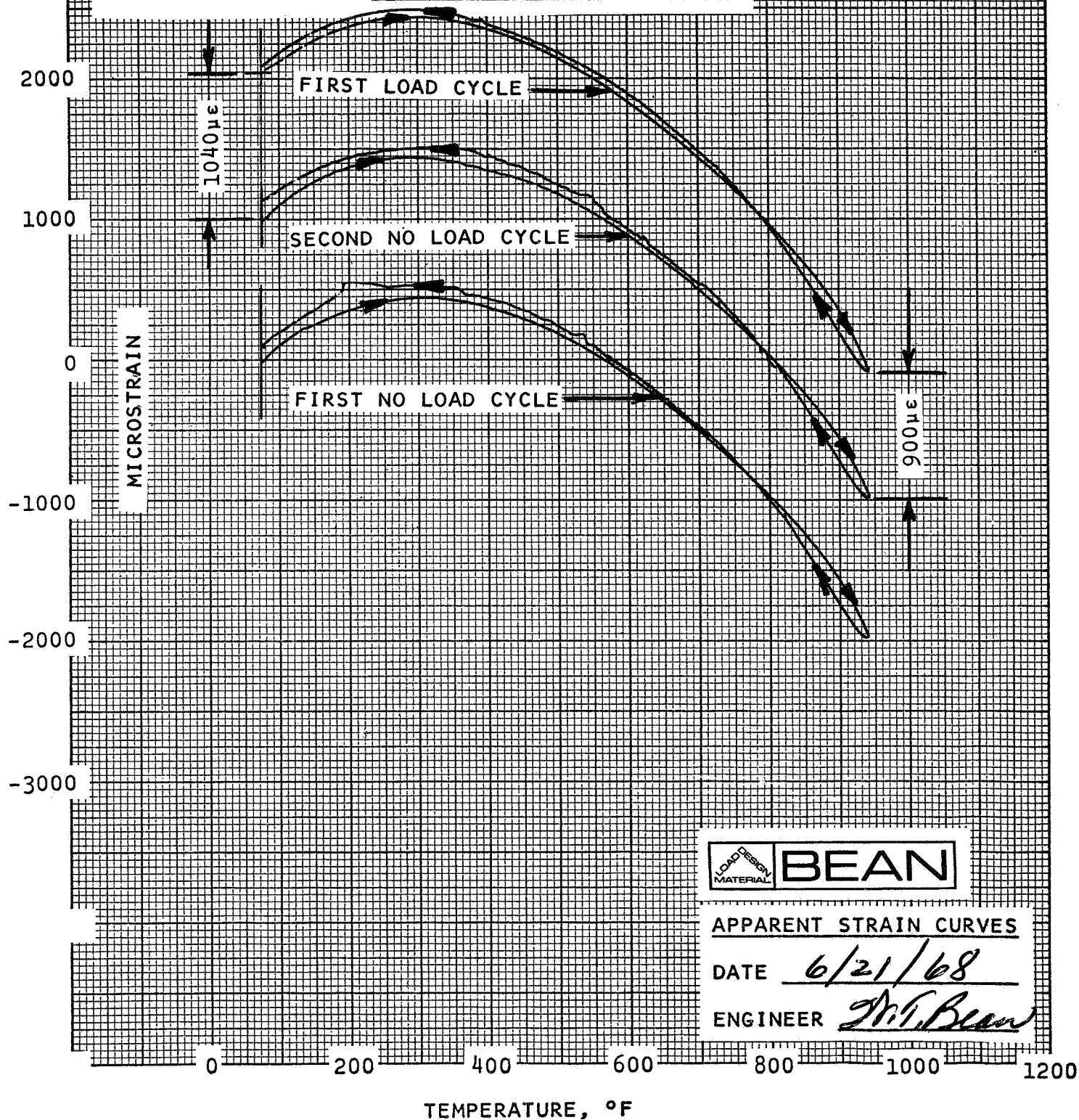
ENGINEER W.F. Bean

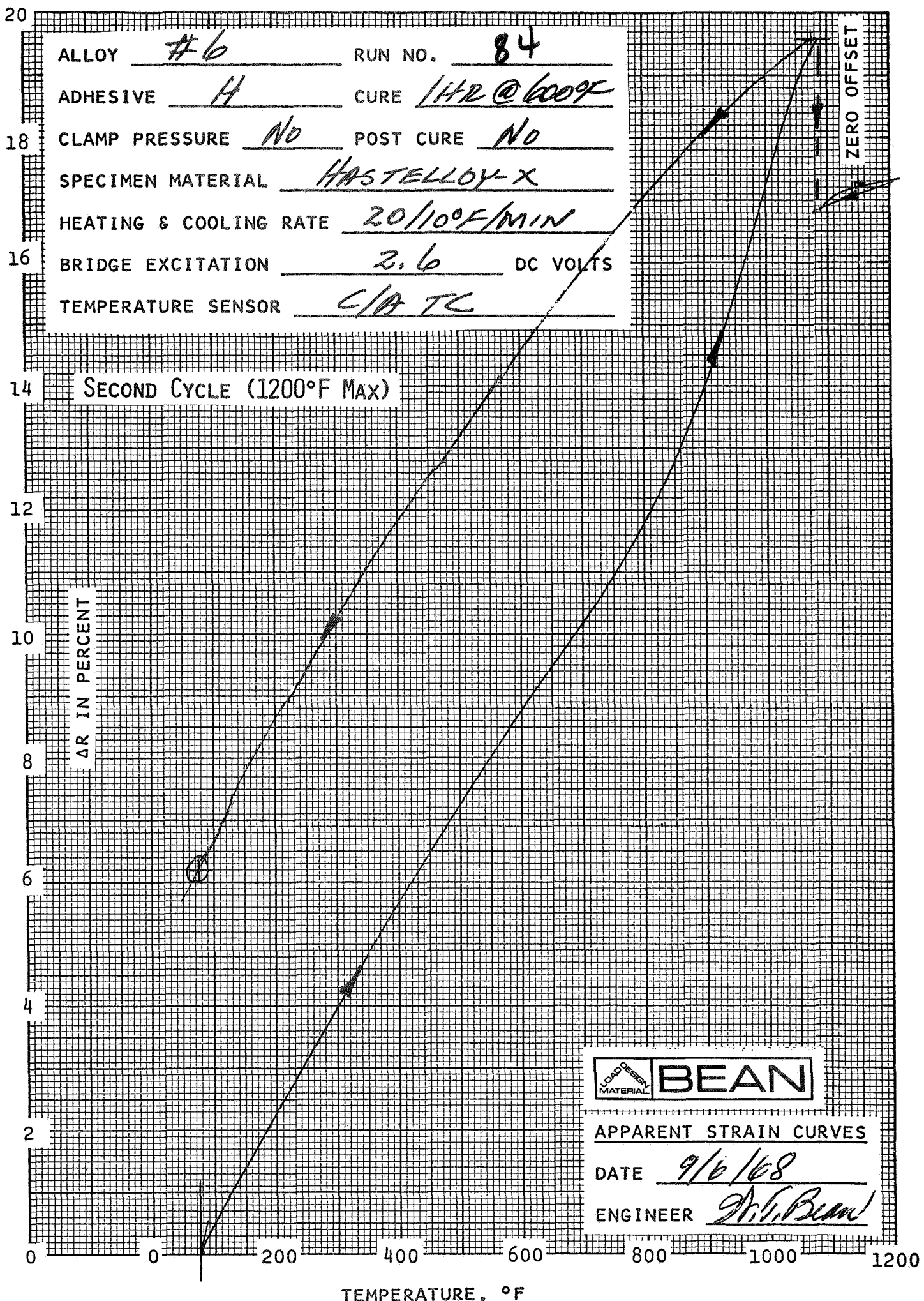
TEMPERATURE, °F

1400

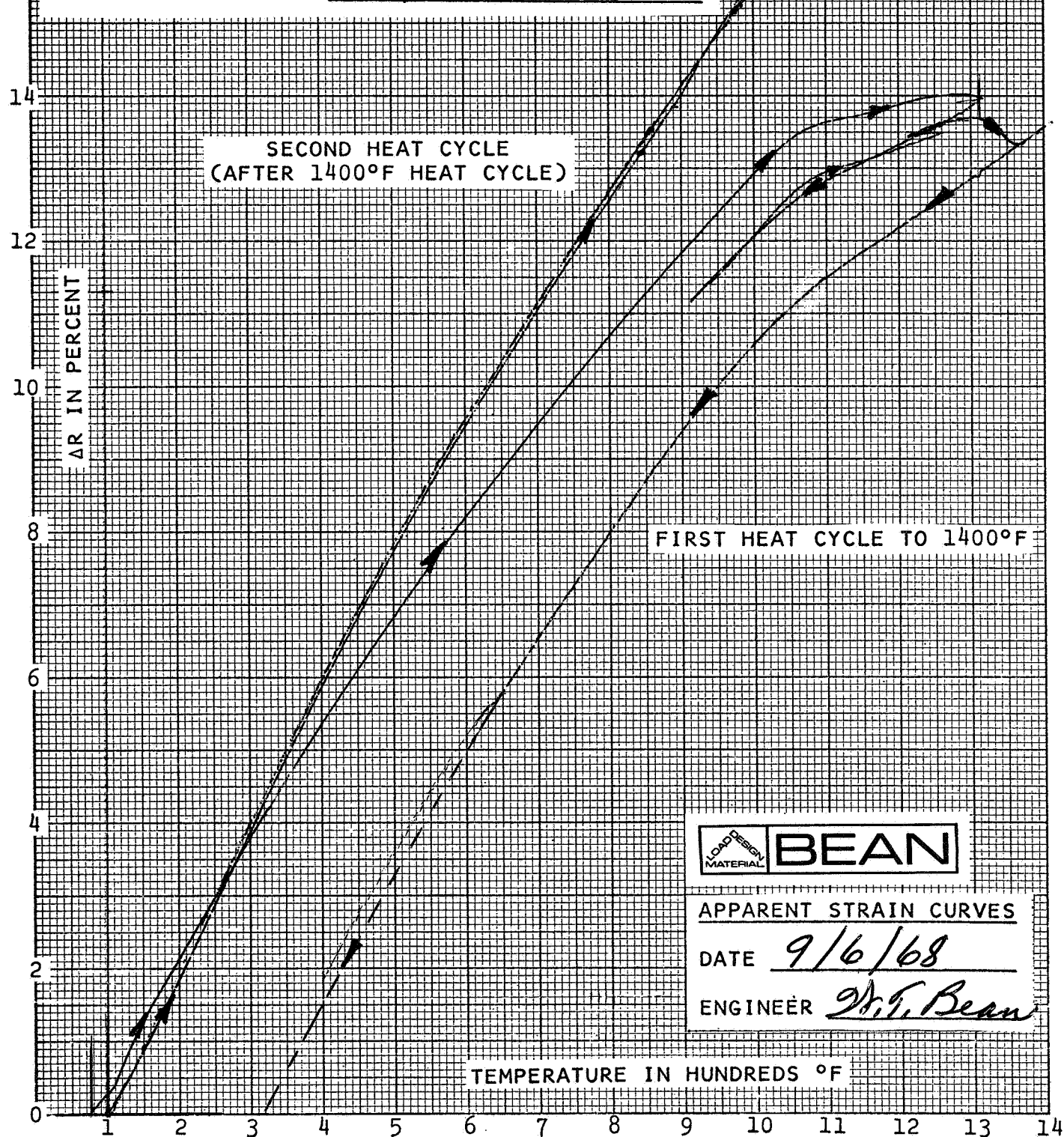


ALLOY #5 RUN NO. 60  
ADHESIVE H CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC

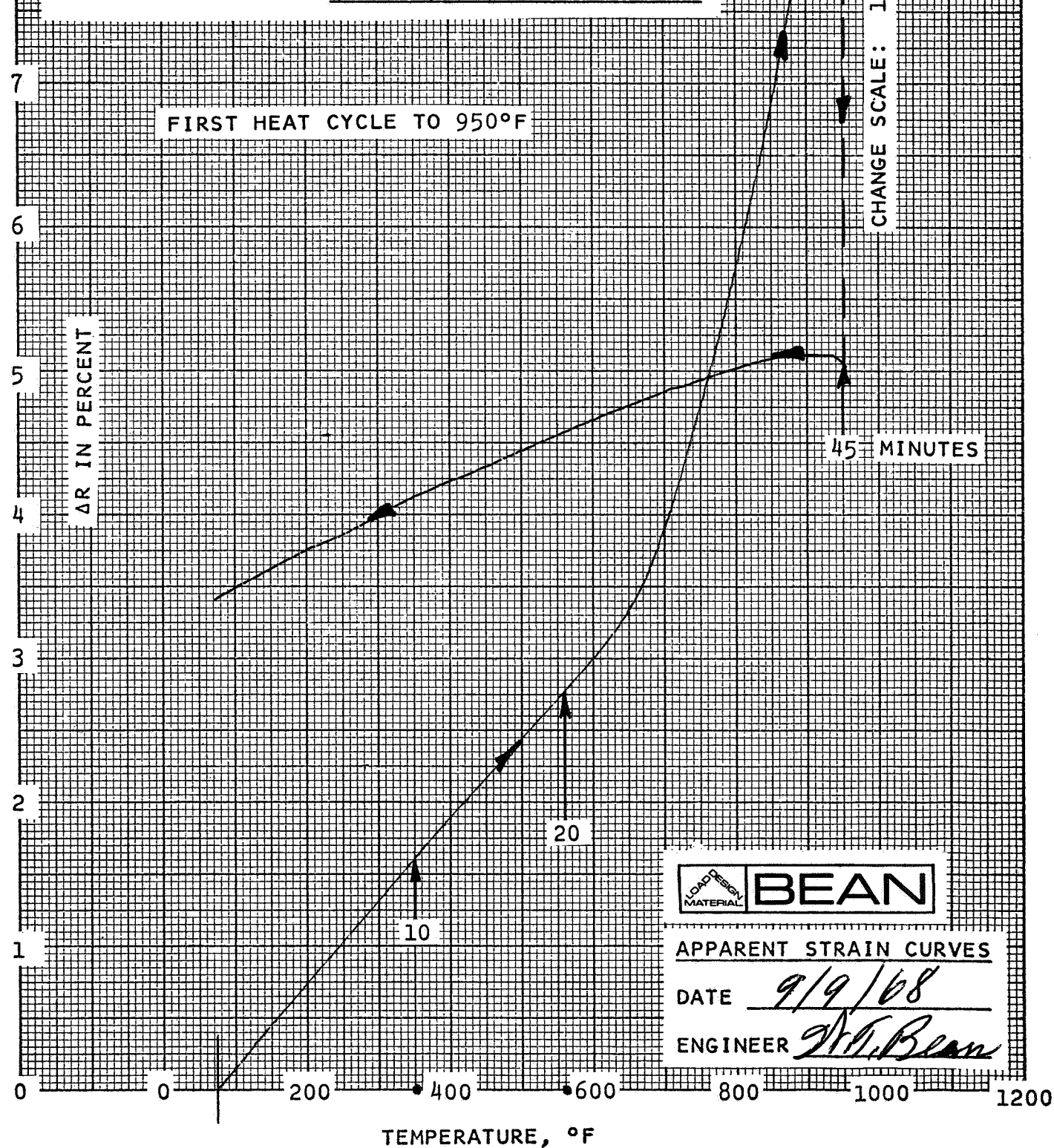




ALLOY #6 RUN NO. 85  
ADHESIVE H CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC

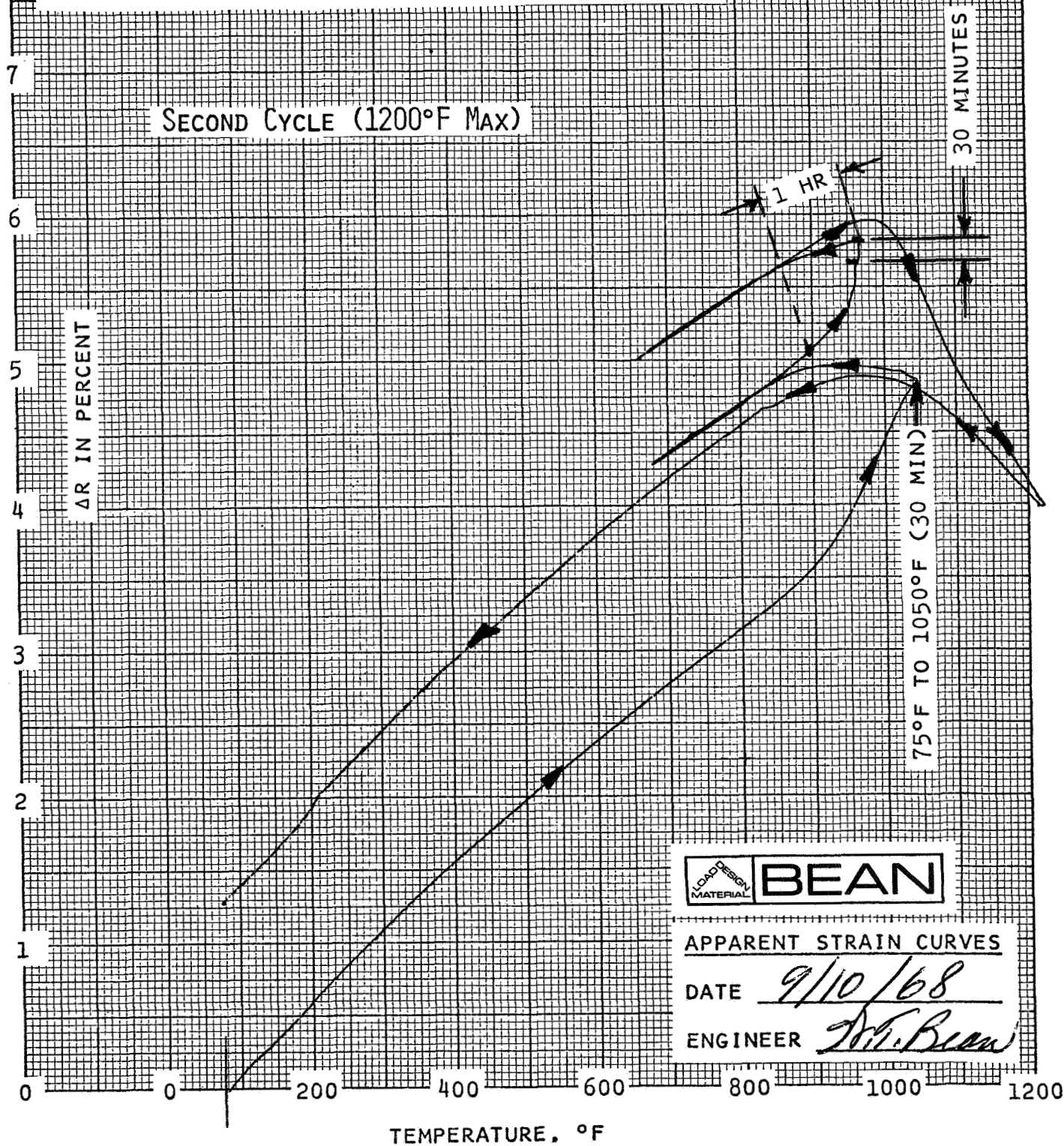


ALLOY #7 RUN NO. 88  
ADHESIVE H CURE 1HR@600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 25/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC



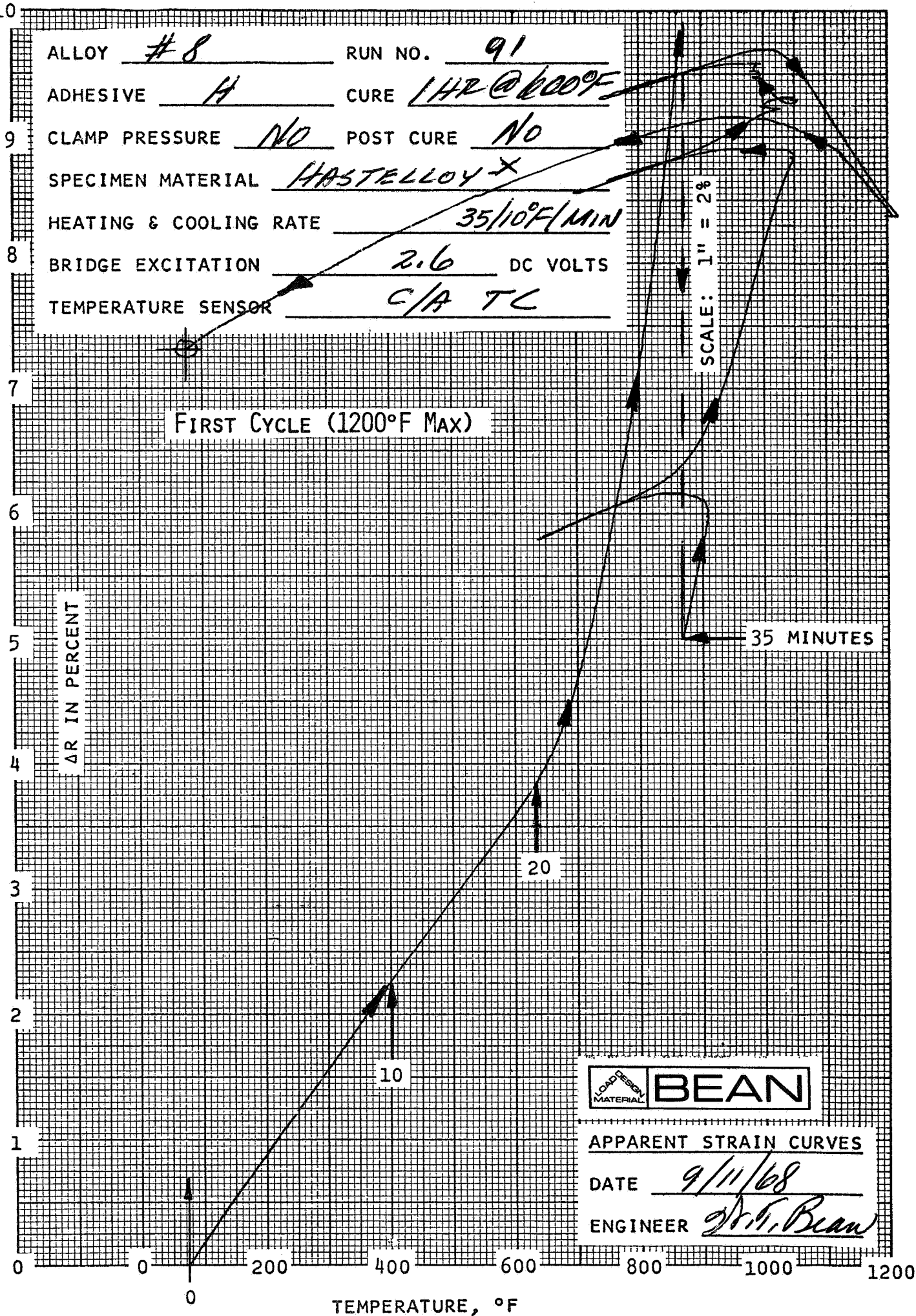


ALLOY #7 RUN NO. 89  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 35/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR CATC





ALLOY #8 RUN NO. 91  
ADHESIVE H CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY X  
HEATING & COOLING RATE 35/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC



10

ALLOY #8 RUN NO. 92ADHESIVE H CURE 1HR @ 600°F9 CLAMP PRESSURE No POST CURE NoSPECIMEN MATERIAL HASTELLOY-XHEATING & COOLING RATE 20/10°F/MIN8 BRIDGE EXCITATION 2.6 DC VOLTSTEMPERATURE SENSOR C/A TC

7

SECOND HEAT CYCLE TO 1200°F

6

ΔR IN PERCENT

5

4

3

2

1

0

0

200

400

600

800

1000

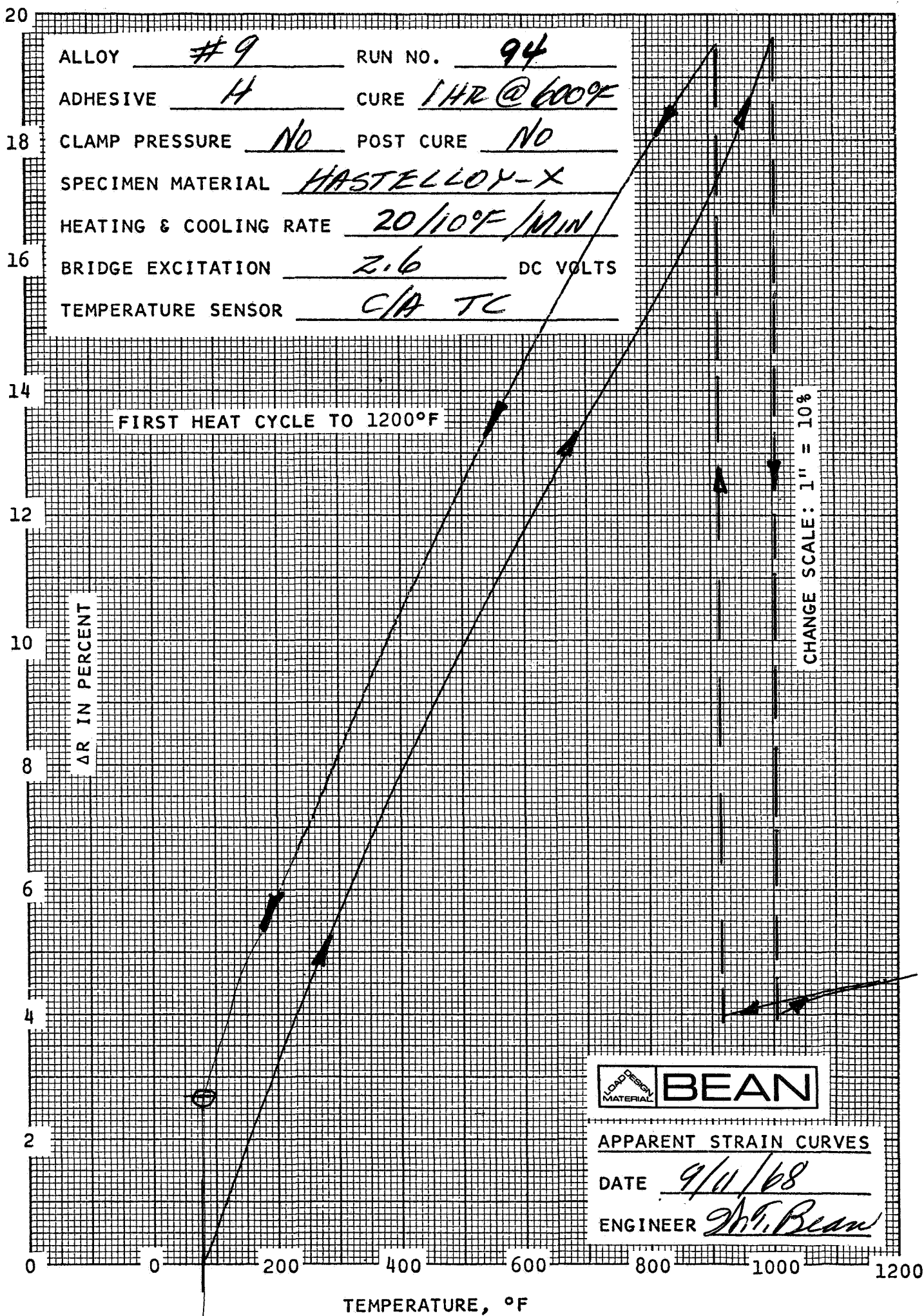
1200

TEMPERATURE, °F

LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 9/12/68ENGINEER W.F. Bean





20

ALLOY #9 RUN NO. 95  
ADHESIVE H CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC

(ZERO OFFSET)

14

12

10

8

6

4

2

 $\Delta R$  IN PERCENT

FIRST HEAT CYCLE TO 1300°F

LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 9/11/68ENGINEER W.T. Bean

TEMPERATURE IN HUNDREDS °F

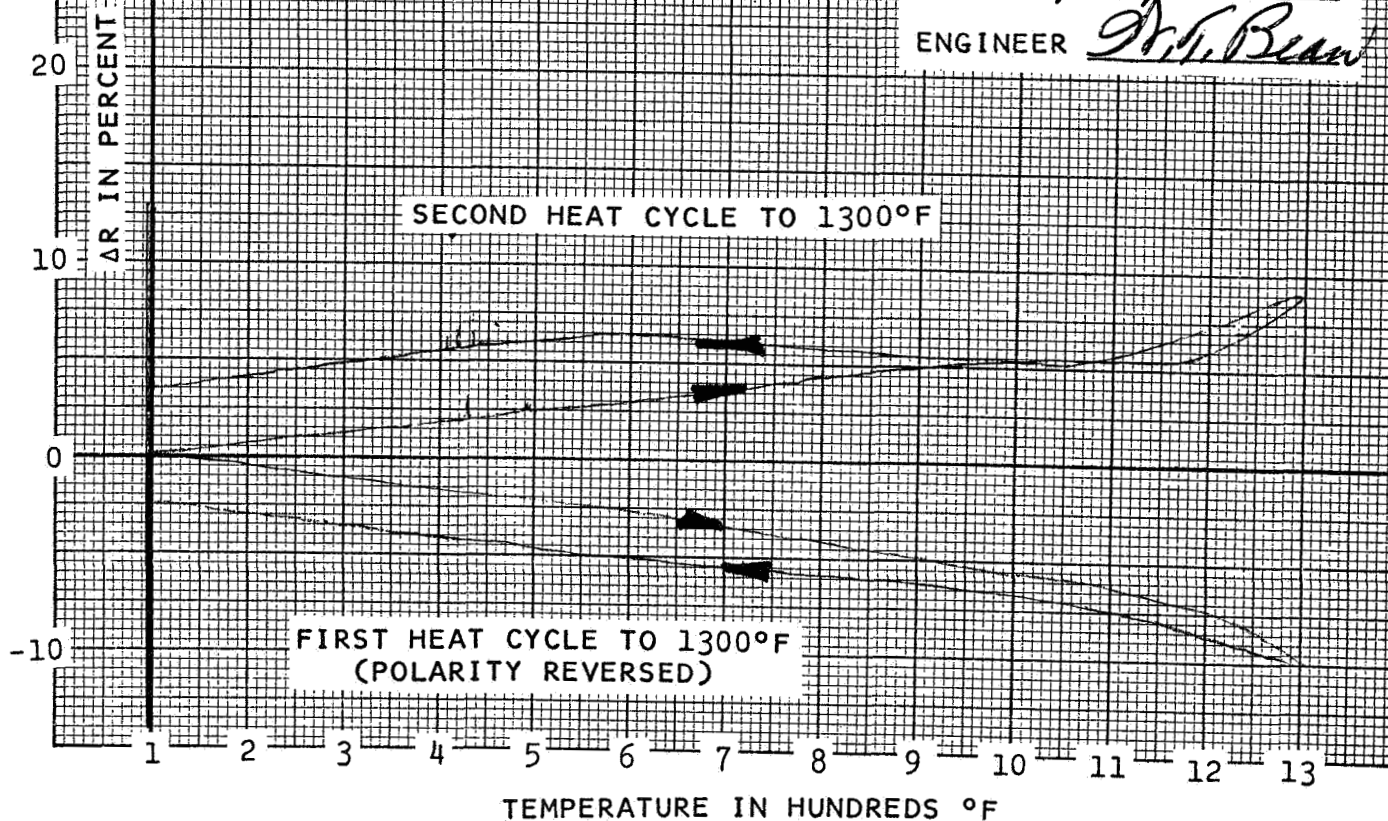
ALLOY #10 RUN NO. 97  
ADHESIVE H CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC

LOAD DESIGN MATERIAL **BEAN**

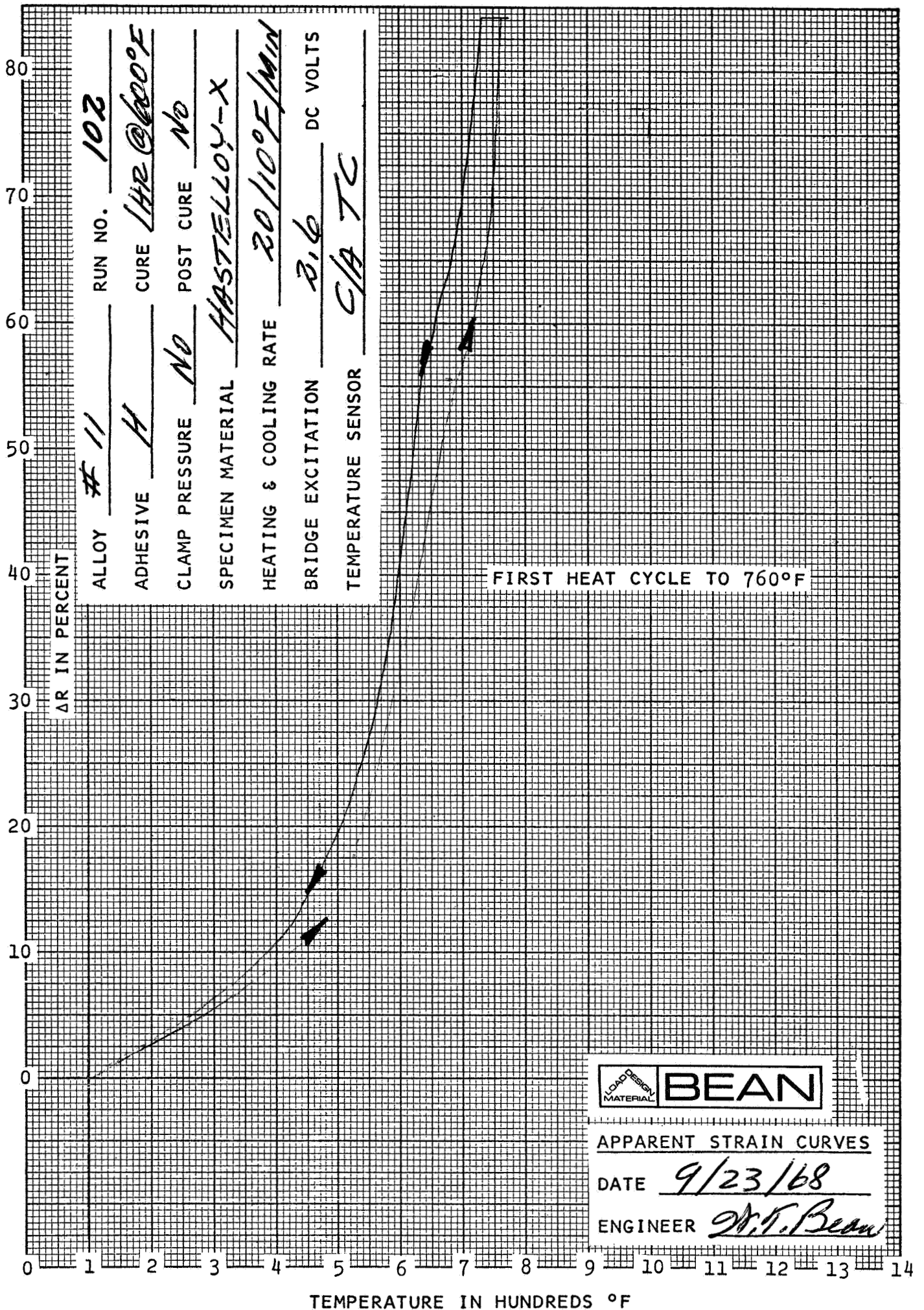
APPARENT STRAIN CURVES

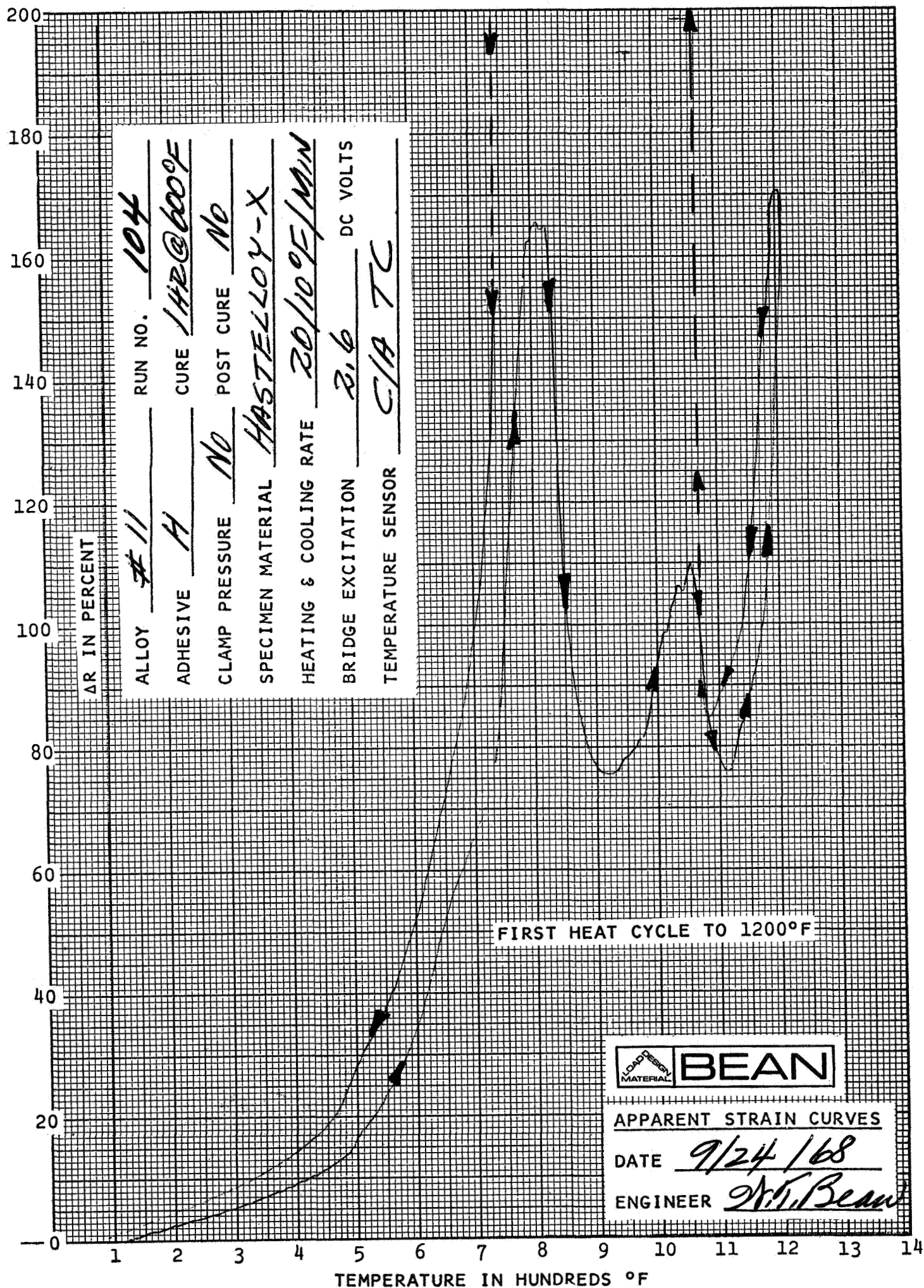
DATE 9/16/68

ENGINEER W. F. Bean









ALLOY #14 RUN NO. 107  
ADHESIVE H CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC

FIRST HEAT CYCLE TO 1200°F

ΔR IN PERCENT

LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

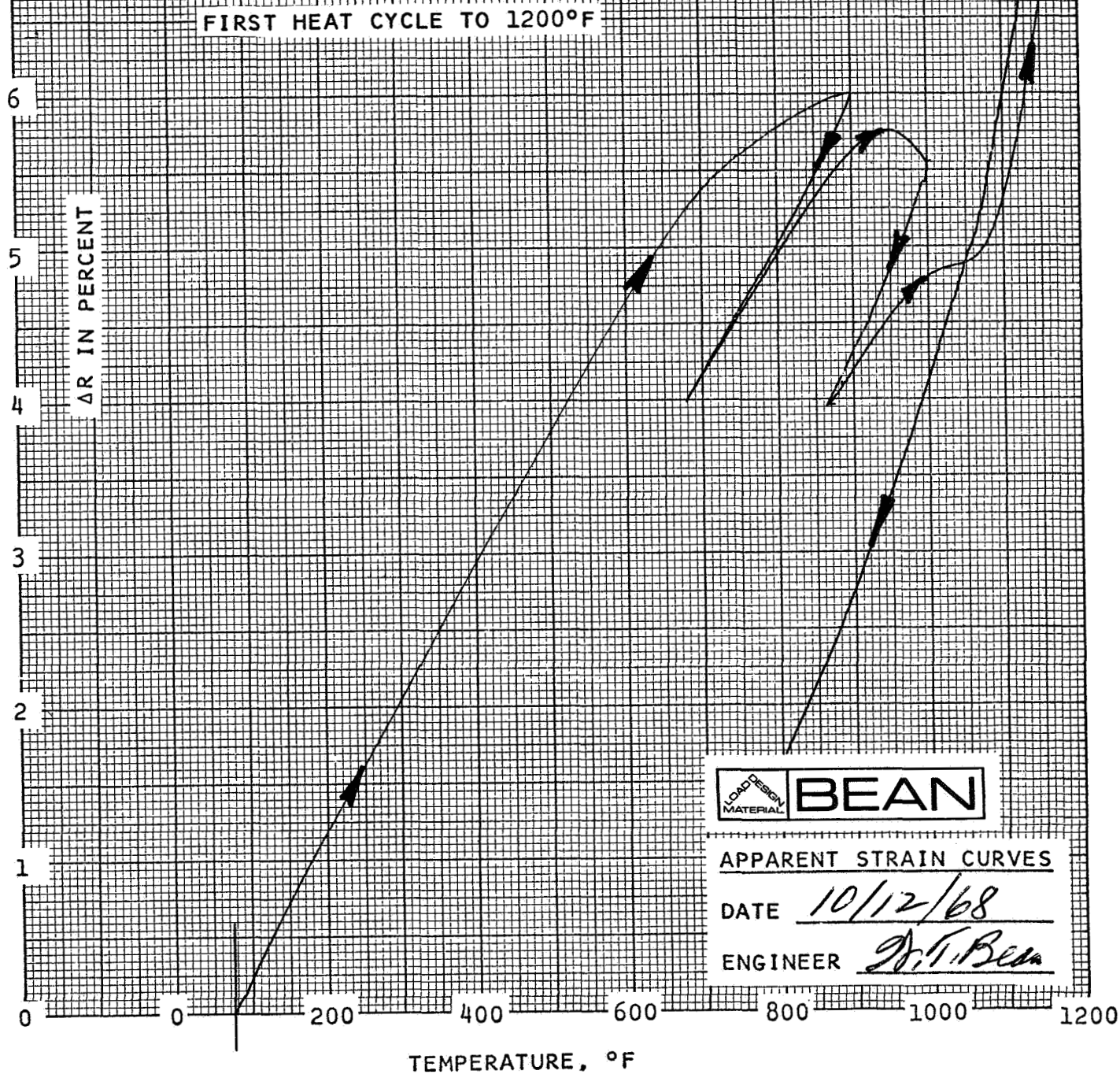
DATE 10/9/68

ENGINEER W.F. Bean

TEMPERATURE, °F



10  
ALLOY #15 RUN NO. 109  
ADHESIVE H CURE 1HR@600°F  
9 CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/10°F/MIN  
8 BRIDGE EXCITATION 2.6 DC VOLTS  
TEMPERATURE SENSOR C/A TC



## V. STRAIN GAGE DESIGN

A strain gage grid was designed utilizing platinum Alloys # 13 and # 3 (Figure 7). The grid was cemented to a high-temperature test specimen of Hastelloy-X. Figure 8 shows the various apparent strain curves obtained by stabilization at 1300°F.

Tests also were conducted with various lengths of the compensating filament, Alloy # 3, in order to rotate the temperature coefficient (T-C) curve (Runs # 202, # 203, and # 209). These runs are compared in Figure 9.

Temperature compensated strain gages were designed and tested on the materials listed in Table VIII. The gage may be designed for other materials by using Figures 10 and 11.



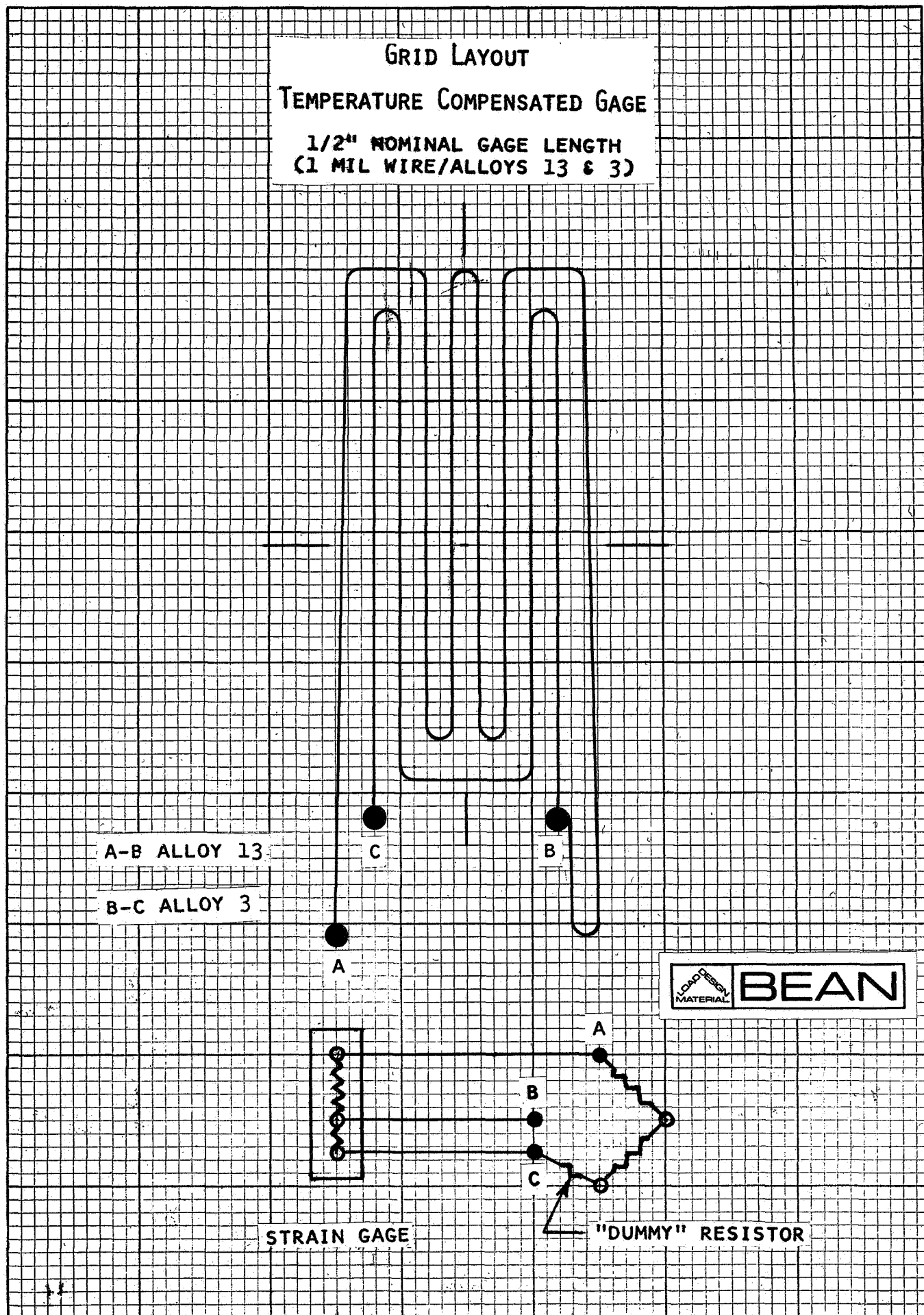


FIGURE 7.

ALLOY #13/#3 RUN NO. SUMMARY  
ADHESIVE H CURE 1 HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/100°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

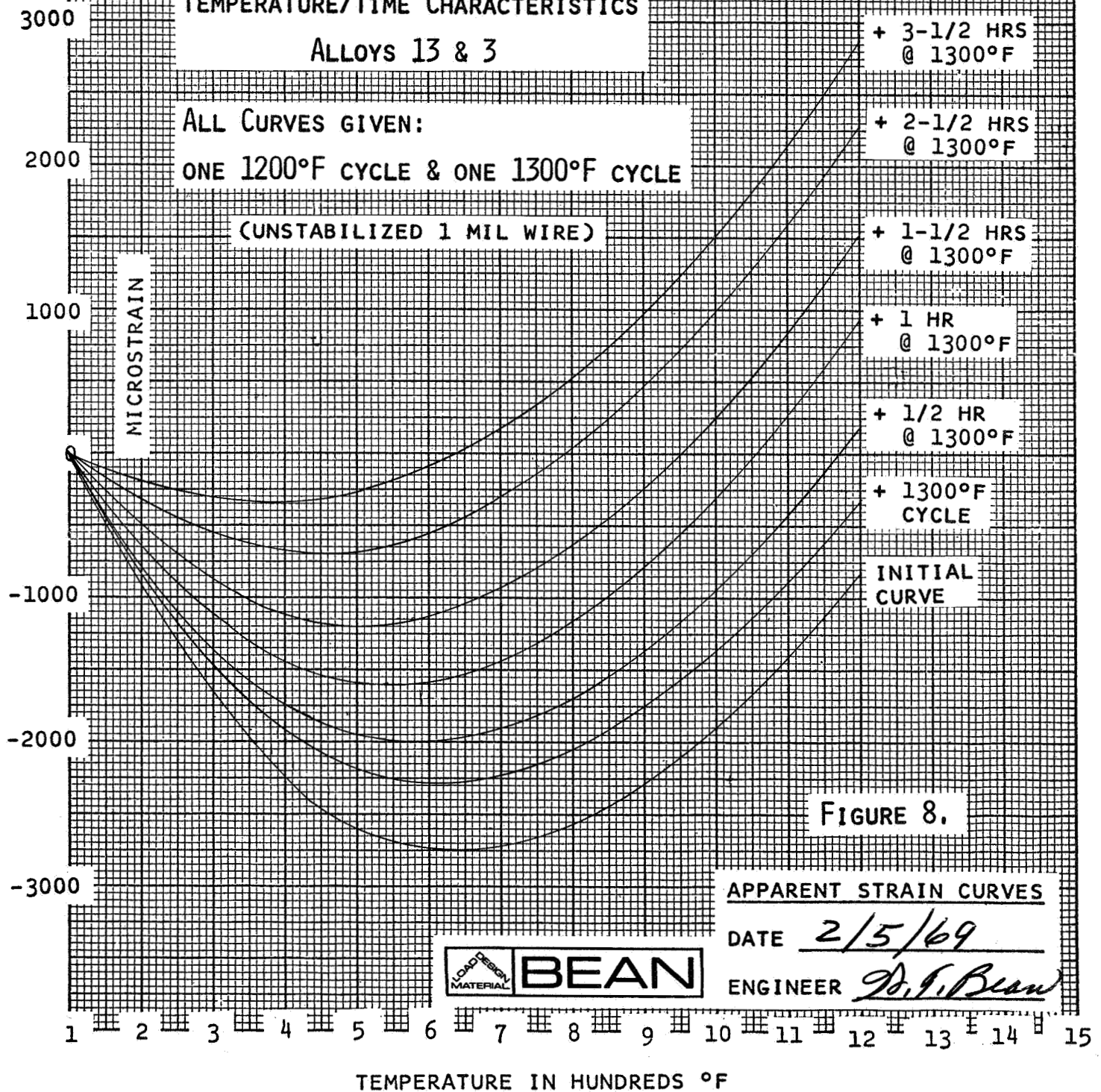
### TEMPERATURE/TIME CHARACTERISTICS

ALLOYS 13 & 3

ALL CURVES GIVEN:

ONE 1200°F CYCLE & ONE 1300°F CYCLE

(UNSTABILIZED 1 MIL WIRE)

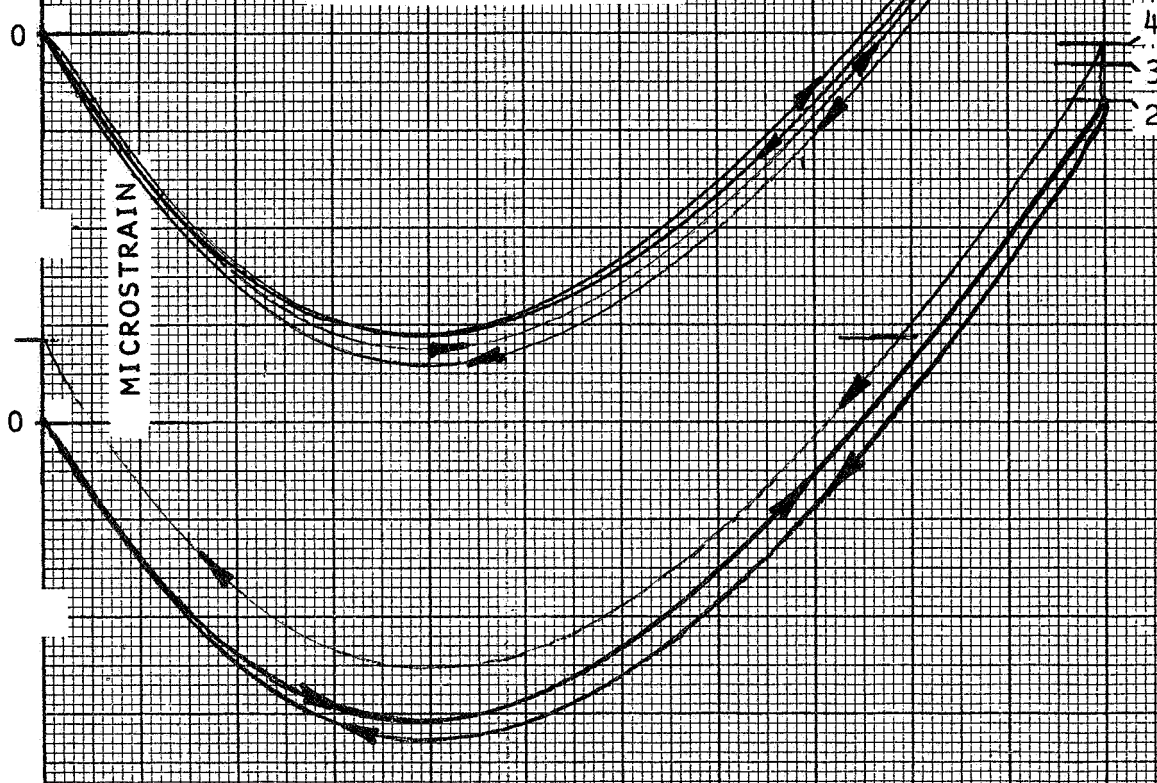


ALLOY #13/#3/HB RUN NO. 202  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

1 MIL WIRE

(1) THREE HEAT CYCLES (1200°F MAX)

SCALE: 1" = 1000 $\mu$ e



(2) PLUS TWO HEAT CYCLES (1200°F MAX)  
(ZERO OFFSET)

(3) HEAT TO 1200°F & HOLD FOR 15 MIN

(4) 30 MIN @ 1200°F

LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 2/15/69

ENGINEER M. F. Bean

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

TEMPERATURE IN HUNDREDS °F



ALLOY #13/#3/HB RUN NO. 203  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

- (1) THREE HEAT CYCLES (1200°F MAX)  
(2) PLUS ONE HEAT CYCLE (1200°F MAX)  
(ZERO OFFSET)  
(3) HEAT TO 1200°F & HOLD FOR 15 MIN  
(4) 30 MIN @ 1200°F
- 1 MIL WIRE

SCALE: 1" = 1000 $\mu$ e

MICROSTRAIN

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

TEMPERATURE IN HUNDREDS °F



APPARENT STRAIN CURVES

DATE 2/17/69

ENGINEER M.F. Bean



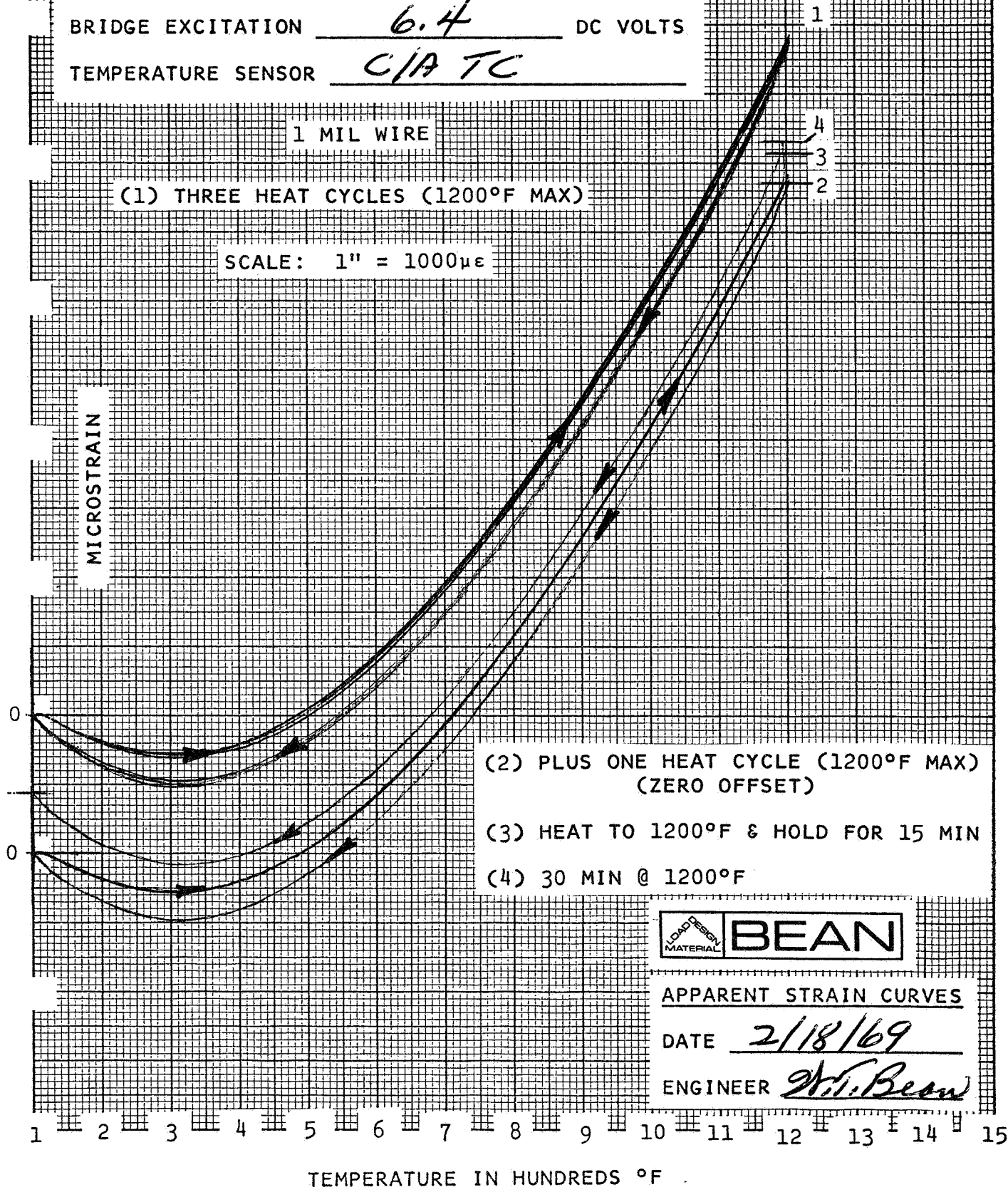
ALLOY #13/#3/HB RUN NO. 209  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

1 MIL WIRE

(1) THREE HEAT CYCLES (1200°F MAX)

SCALE: 1" = 1000 $\mu\epsilon$

MICROSTRAIN



ALLOY #13/43/HB RUN NO. 202, 203, 209

ADHESIVE H-1 CURE 1HR@600°F

5000 CLAMP PRESSURE No POST CURE No

SPECIMEN MATERIAL HASTELLOY-X

HEATING & COOLING RATE 20/20°F/MIN

4000 BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC

RUN #209

RUN NO.	LENGTH IN INCHES	
	#13	#3
202	8-5/16	4-5/8
203	8-5/16	4-7/8
209	8-5/16	4-3/8

RUN #202

RUN #203

FIGURE 9.

LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 2/18/69

ENGINEER W.F. Bean

5000

4000

3000

2000

1000

0

-1000

-2000

-3000

MICROSTRAIN

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

TEMPERATURE IN HUNDREDS °F

Table VIII

**STRAIN GAGE ALLOYS 13 & 3**  
**Typical Compensating Elements**  
**for**  
**120 Ohm Gages\***  
 (Based on 1 Mil Wire)

Specimen Material	Expansion Coefficient PPM/°F	Length in Inches	Compensating Resistance Ohms	"Dummy" Resistance Ohms
Zirconium	3.1	2-3/32	34.95	85.05
Titanium	4.9	2-3/16	36.51	83.49
17-4 PH	6.0	2-7/32	37.03	82.97
Hastelloy-X	7.7	2-11/32	39.12	80.88
304 SS	9.3	2-13/32	40.16	79.84

\*Nominal length of 120  $\Omega$  active element (#13) is 4-3/16" @ 75°F

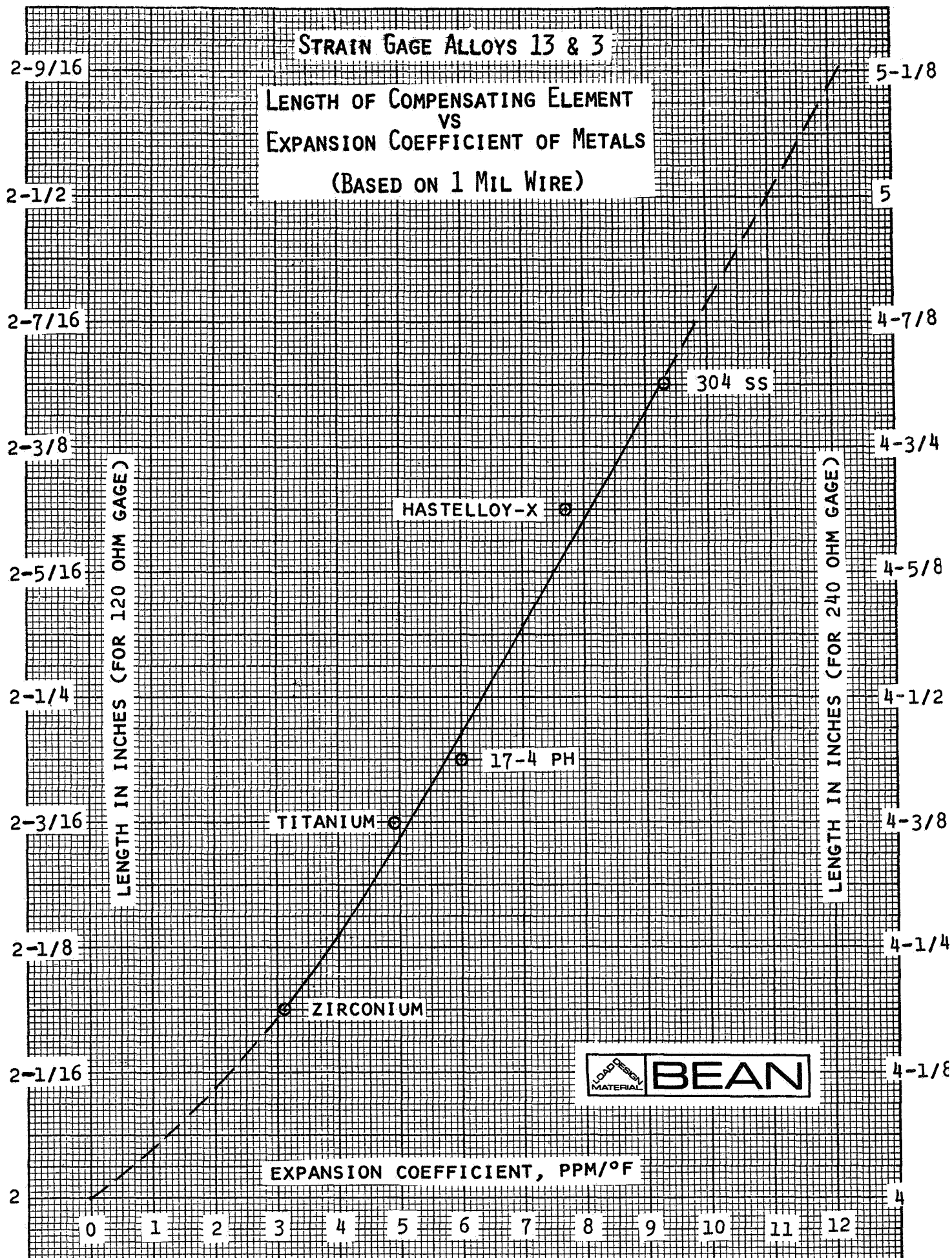


FIGURE 10.



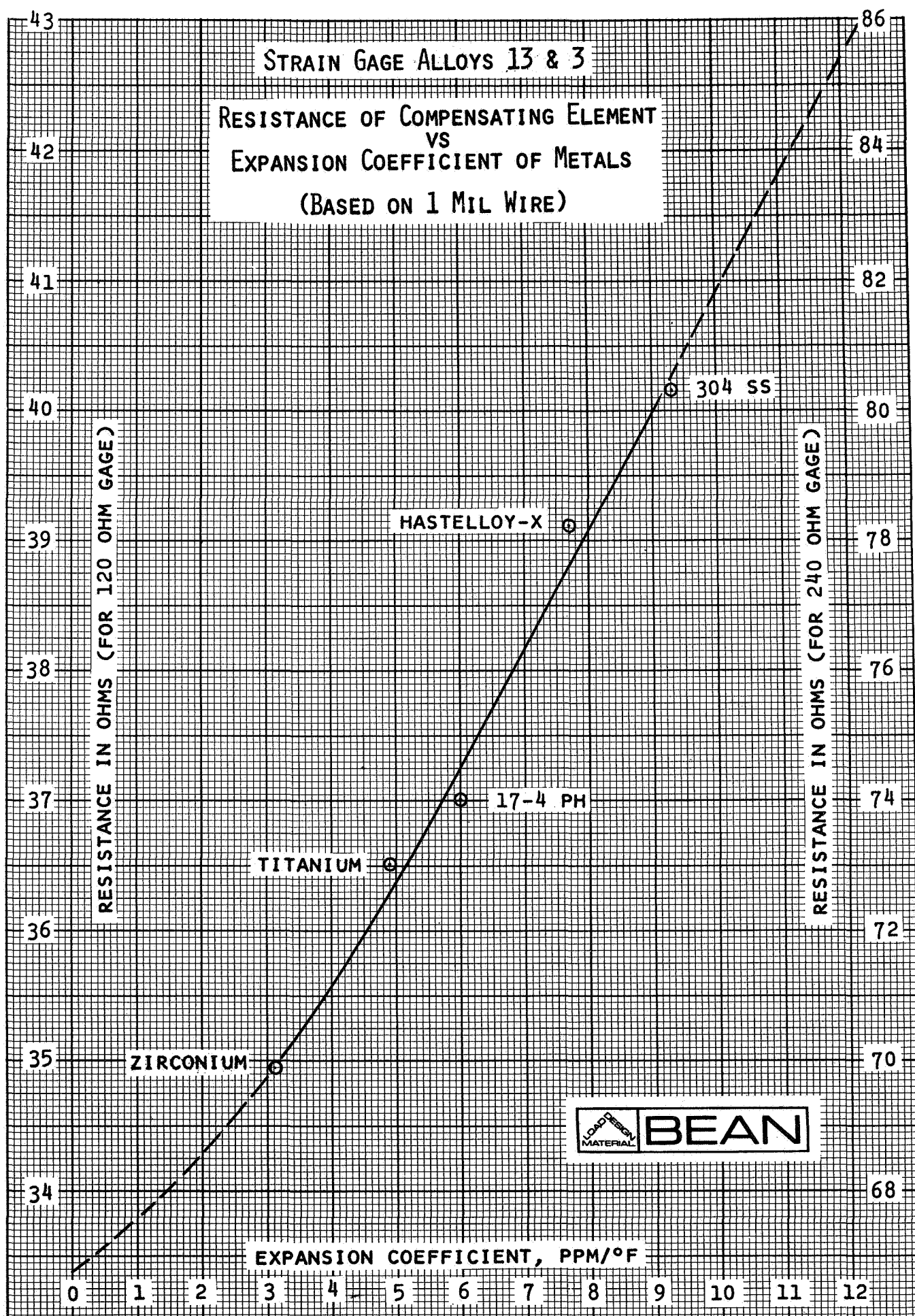


FIGURE 11.

## VI. STRAIN GAGE EVALUATION

### Temperature Compensation

Using the preceding information, apparent strain curves were obtained as follows:

<u>Specimen Material</u>	<u>Run No.</u>
Aluminum, 2024	234
Zirconium	223
Titanium, 6AL4V	211
Hastelloy-X	235
Hastelloy-X	230
Stainless Steel, 304	214

During the initial heat cycle a zero offset is evident when the strain gage filament encounters plastic deformation (Runs # 235, # 230, # 214). The magnitude of the offset may be predicted by considering the coefficient of expansion of the specimen material and the applied mechanical strain. The gage filament performs in an elastic manner on the recovery cycle.

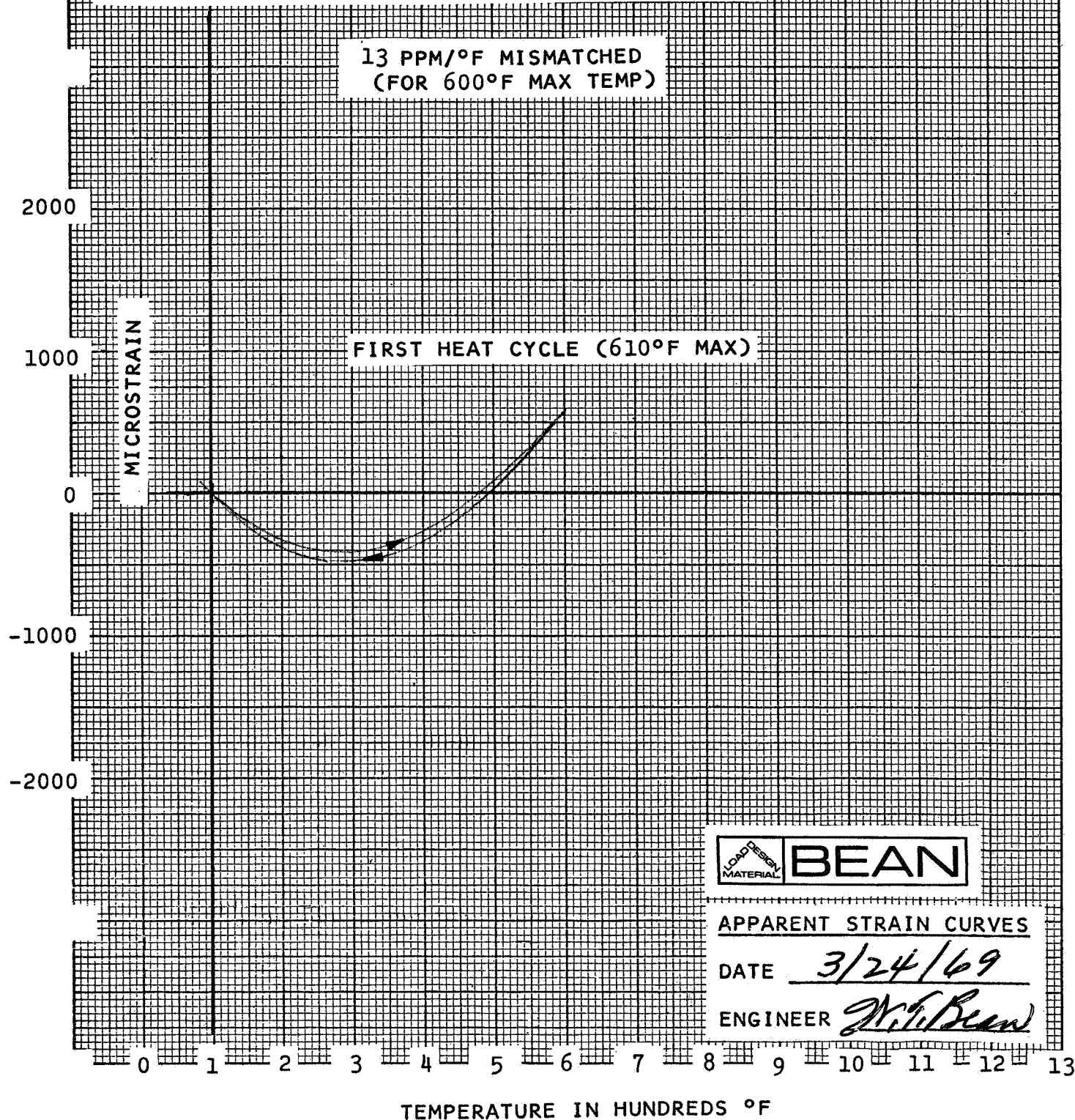
ALLOY #13/#3/HB RUN NO. 234  
ADHESIVE H-1 CURE 1hr@600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL 2024 ANNEALED  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

1 MIL WIRE

#13 8-3/8"

#3 4-11/16"

13 PPM/°F MISMATCHED  
(FOR 600°F MAX TEMP)



LOAD DESIGN MATERIAL **BEAN**

APPARENT STRAIN CURVES

DATE 3/24/69

ENGINEER W. F. Bean

ALLOY #13/#3/HA RUN NO. 223

ADHESIVE H-1 CURE 1HR @ 600°F

CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL ZIRCONIUM

HEATING & COOLING RATE 20/20°F/MIN

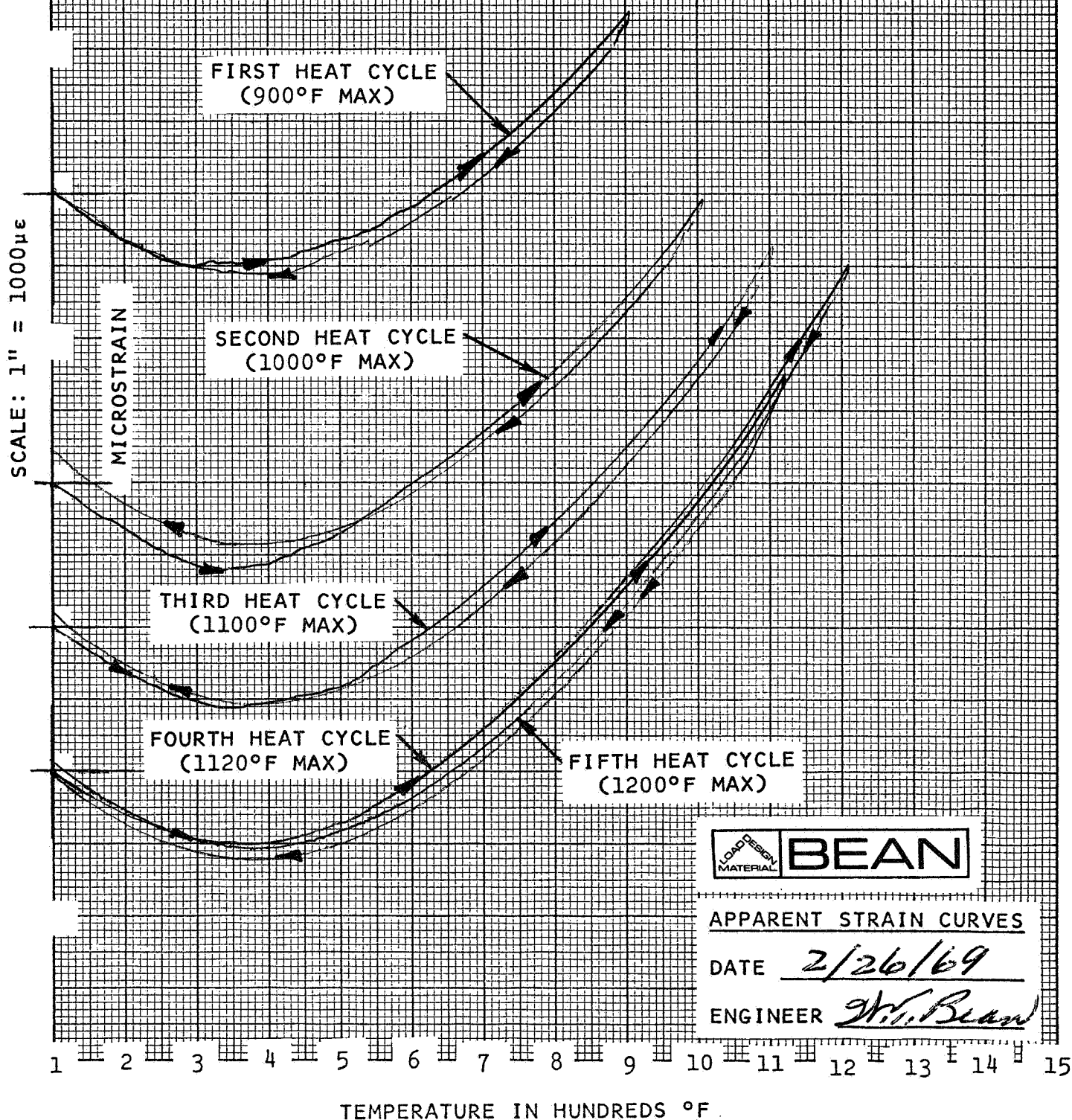
BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC

1 MIL WIRE

#13 8-3/8"

#3 4-1/8"





ALLOY #13/#3/HA RUN NO. 211  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL TITANIUM 6AL-4V  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

1 MIL WIRE

#13 8-3/8"

#3 4-3/8"

SCALE: 1" = 1000µe

MICROSTRAIN

(4) ONE HEAT CYCLE  
(1010°F MAX)

(5) TWO HEAT CYCLES  
(LOADED IN COMPRESSION)

(1) TWO HEAT CYCLES  
(800°F MAX)

(2) TWO HEAT CYCLES  
(1000°F MAX)

(3) ONE HEAT CYCLE  
(1000°F MAX)



**BEAN**

APPARENT STRAIN CURVES

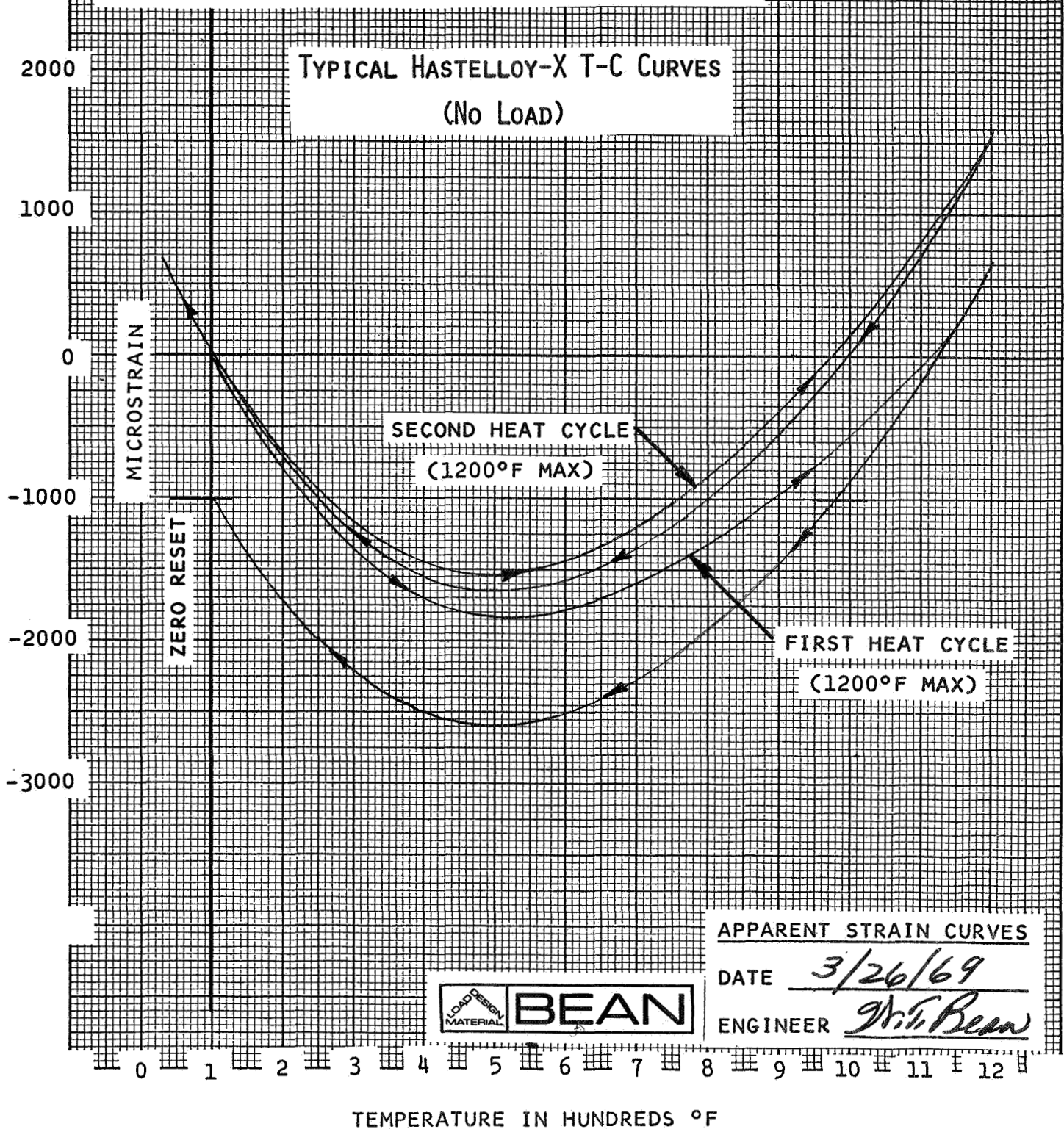
DATE 2/20/69

ENGINEER H.F. Bean

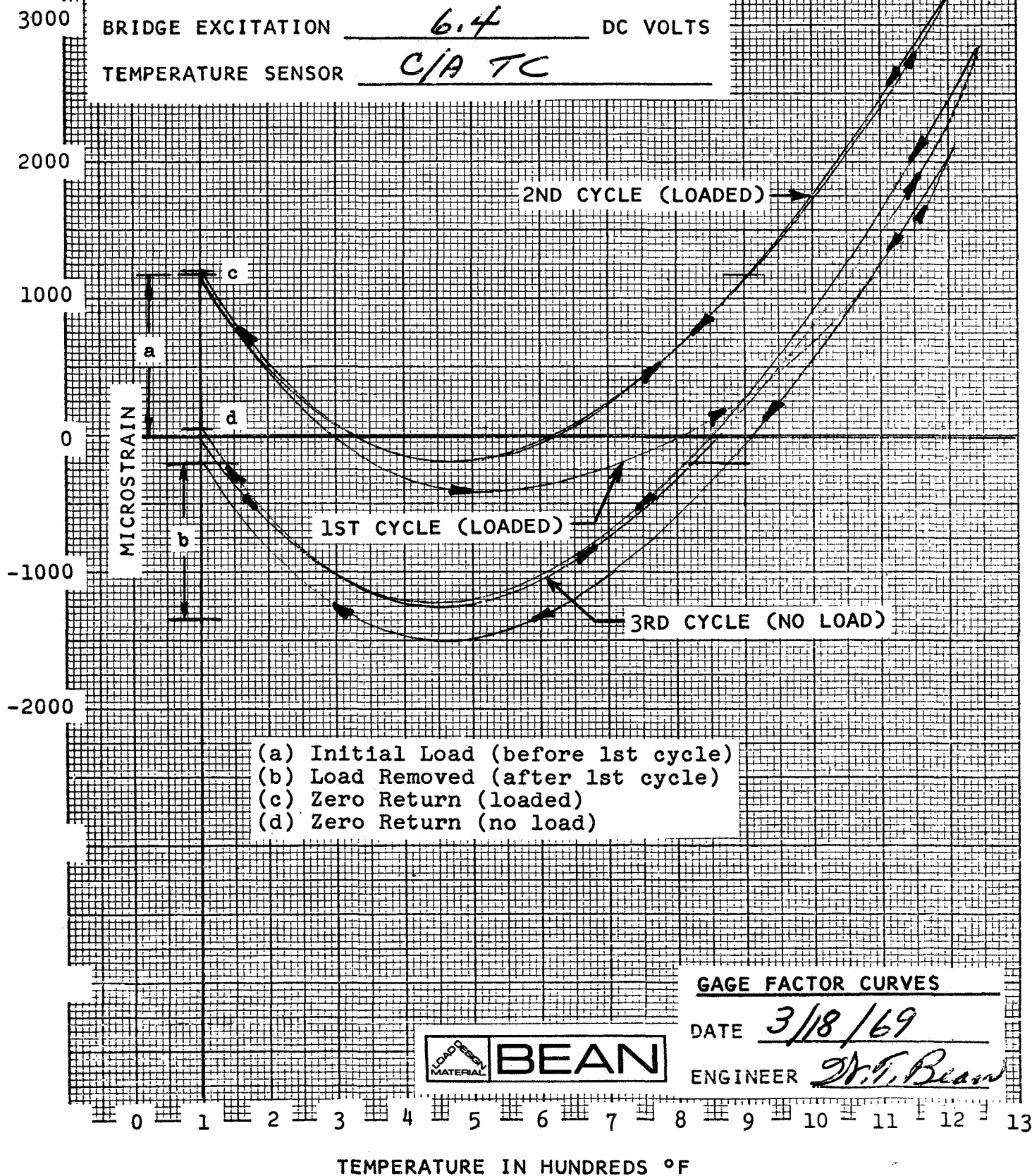
TEMPERATURE IN HUNDREDS °F

ALLOY #13/#3/HB RUN NO. 235  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X 1/16"  
HEATING & COOLING RATE 100/50°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

1 MIL WIRE  
#13 8-3/8"  
#3 4-5/8"



ALLOY #13/#3/HB RUN NO. 230  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X (1/8")  
HEATING & COOLING RATE 30/40°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC



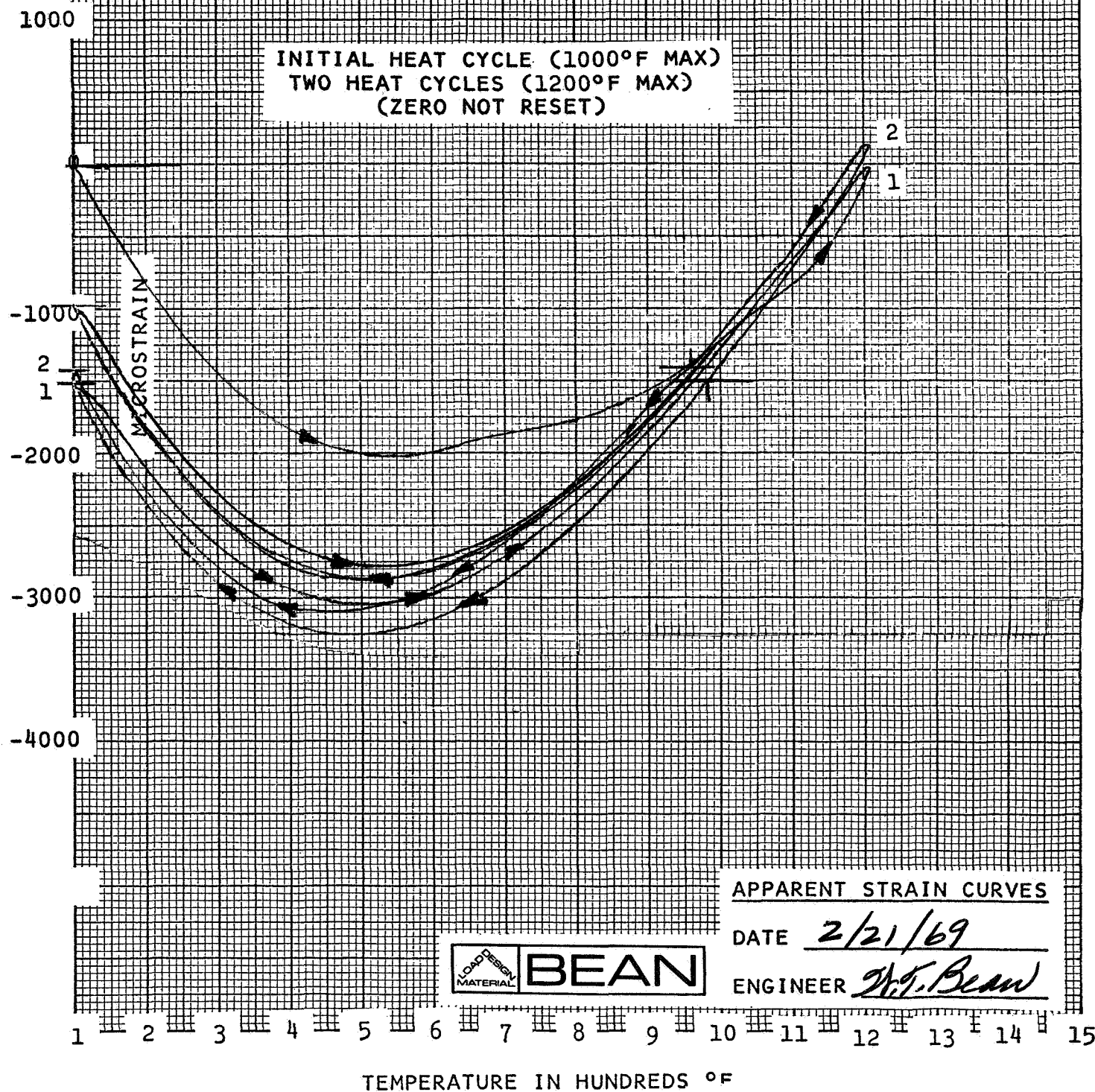
GAGE FACTOR CURVES

DATE 3/18/69  
ENGINEER Dr. F. Bevan

LOAD DESIGN MATERIAL **BEAN**



ALLOY #13/#3/HB RUN NO. 214  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL 304SS (1/4")  
HEATING & COOLING RATE 10/20°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC





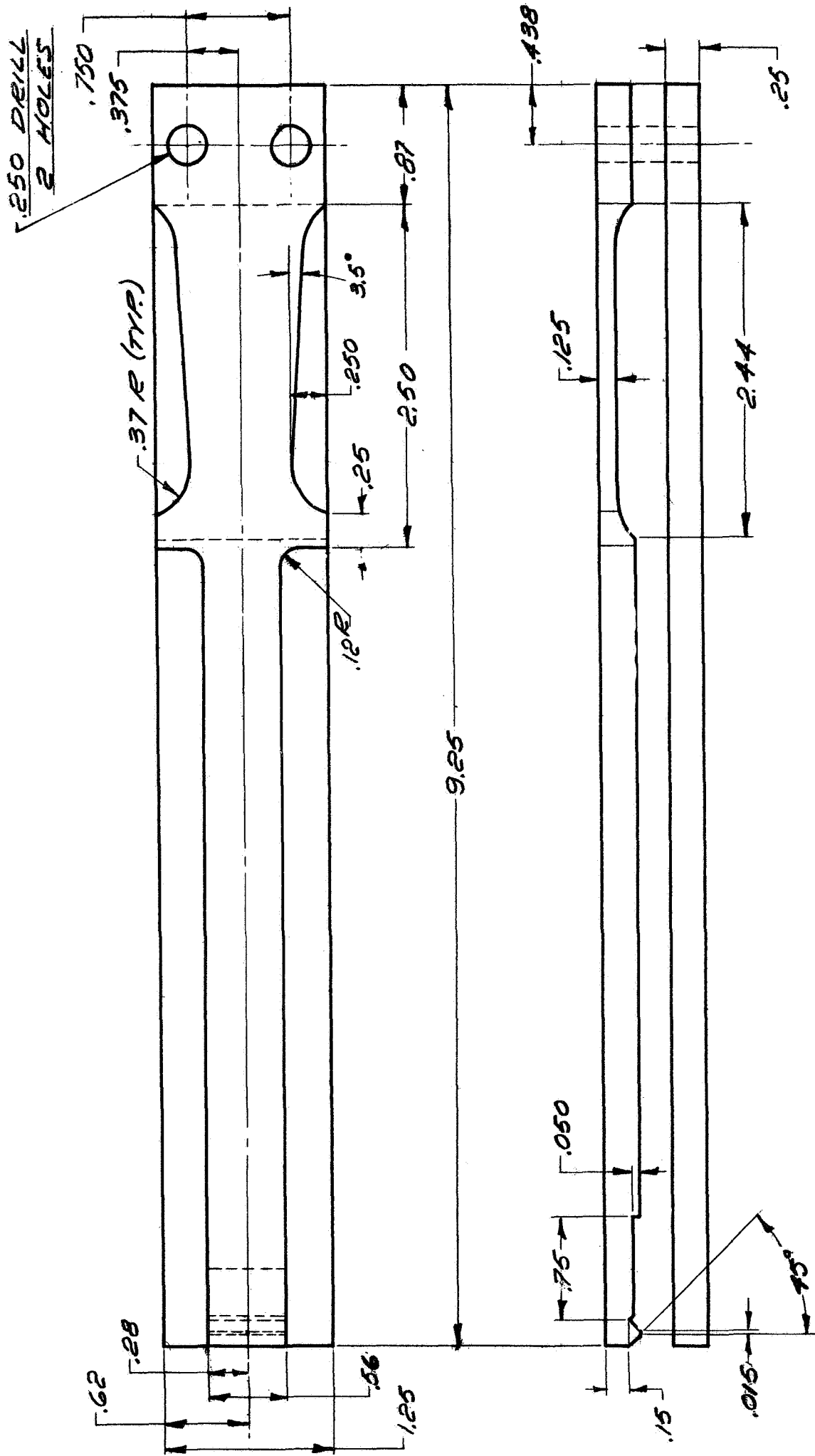
### Gage Factor vs. Temperature

In order to determine gage factor vs. temperature, a strain gage was mounted on the gage-factor calibration bar (Figure 12). "First" cycle point-by-point data was obtained at various temperatures (Table IX). The second cycle T-C curve is shown (Run # 200). The third heat cycle (no load) is compared with the fourth heat cycle (fixture loaded) (Run # 201). The reduction in gage factor with increasing temperature is apparent from closer ordinate spacing at higher temperatures.

Table X is a record of a test conducted by mounting a similar gage on a second calibration bar. A Time/Temperature Chart of the test is shown (Figure 13). Run # 221 charts the initial (no load) heat cycle. Approximately eight hours of testing followed (Run # 222).

Run # 219 indicates the zero offset obtained from a strain gage with an alternate heat treatment. Tables XI and XII list the test record of a strain gage mounted on a similar fixture. The fixture was fabricated from J1650, a "Superalloy" used for gas turbine blades. The Time/Temperature Chart is shown in Figure 14. Approximately twenty hours of test results are graphically presented in Runs # 224, # 225, # 226. Results of numerous gage factor vs. temperature tests were plotted (Figure 15).

Two gages were mounted in a back-to-back (bending) configuration on the test specimen (Figure 4). The T-C curves of each gage were compared (Runs # 144, # 145). Load and no load runs were conducted, using different pin diameters in the fixture. Run # 146 was conducted using 1/4" pins, while Run # 147 was conducted with 3/16" pins. The results are in agreement with data from Figure 15.



CALIBRATION BAR

12-18-57

DESIGNED W. T. BEAN JR.

DRAWN H. J. J.

SCALE: FULL SIZE

FIGURE 12.

Table IX

Gage Factor vs Temperature

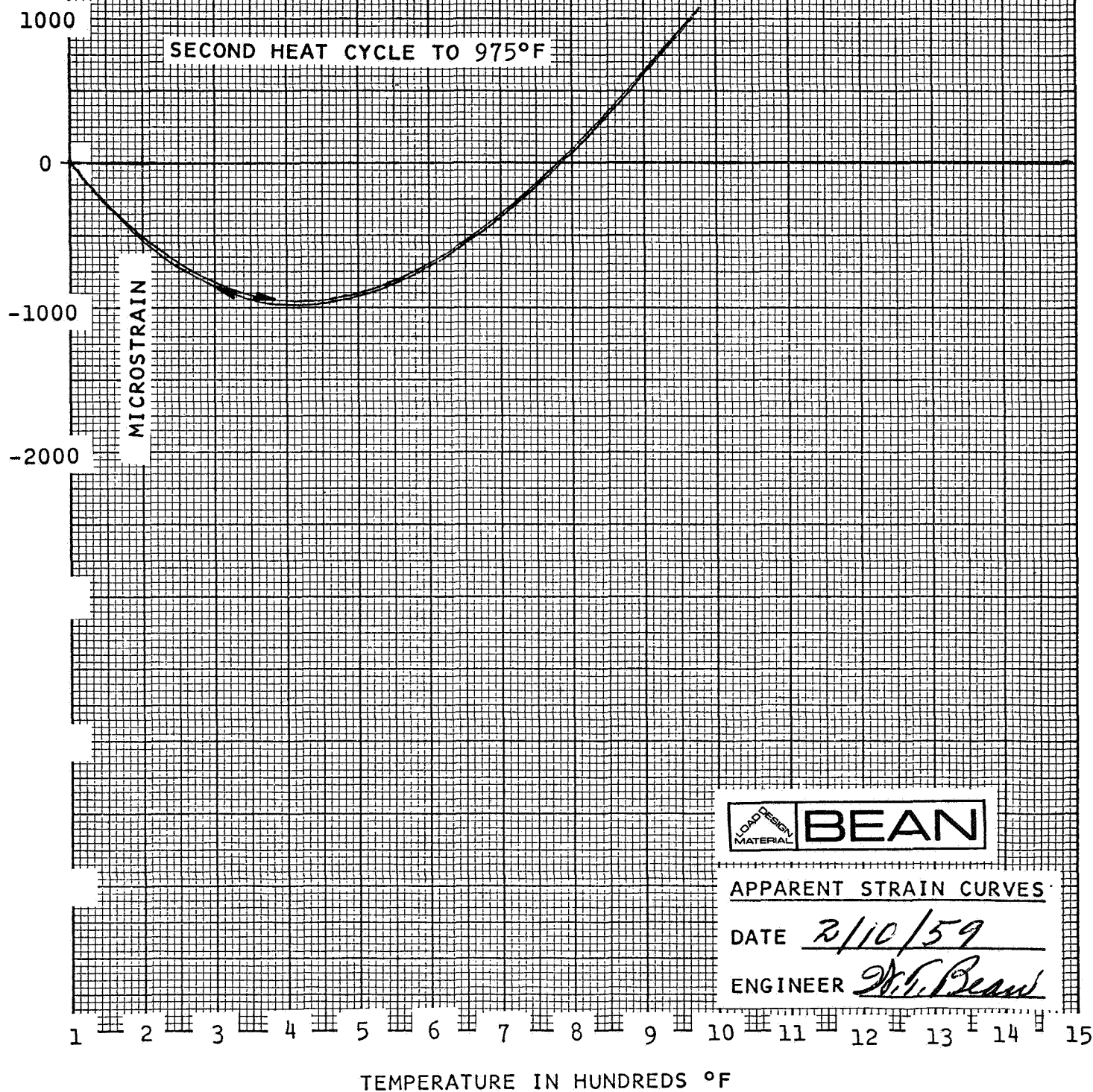
First Cycle Point by Point Data\*  
(Prior to Runs #200 & #201)

Test Temperature	Apparent Strain	Load Strain	Percent G.F./100°F
100°F	0 $\mu\epsilon$	586 $\mu\epsilon$	100.0
250	-711	555	94.7
400	-970	525	89.6
450	-981	---	---
600	-724	492	84.0
786	0	---	---
800	42	465	79.4
975	1045	451	77.0
800	46	463	79.0
600	-758	492	84.0
500	-961	---	---
400	-1012	525	89.6
250	-737	---	---
100	-16	586	100.0

\*17-4 PH Test Fixture, 1/4" Section  
Alloy #13/#3



ALLOY #13/#3/HA RUN NO. 200  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL 17-4PH (1/4")  
HEATING & COOLING RATE 20/10°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC



ALLOY #13/#3/HA RUN NO. 201  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL 17-4 PH (1/4")  
HEATING & COOLING RATE 35/25°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

THIRD HEAT CYCLE TO 975°F

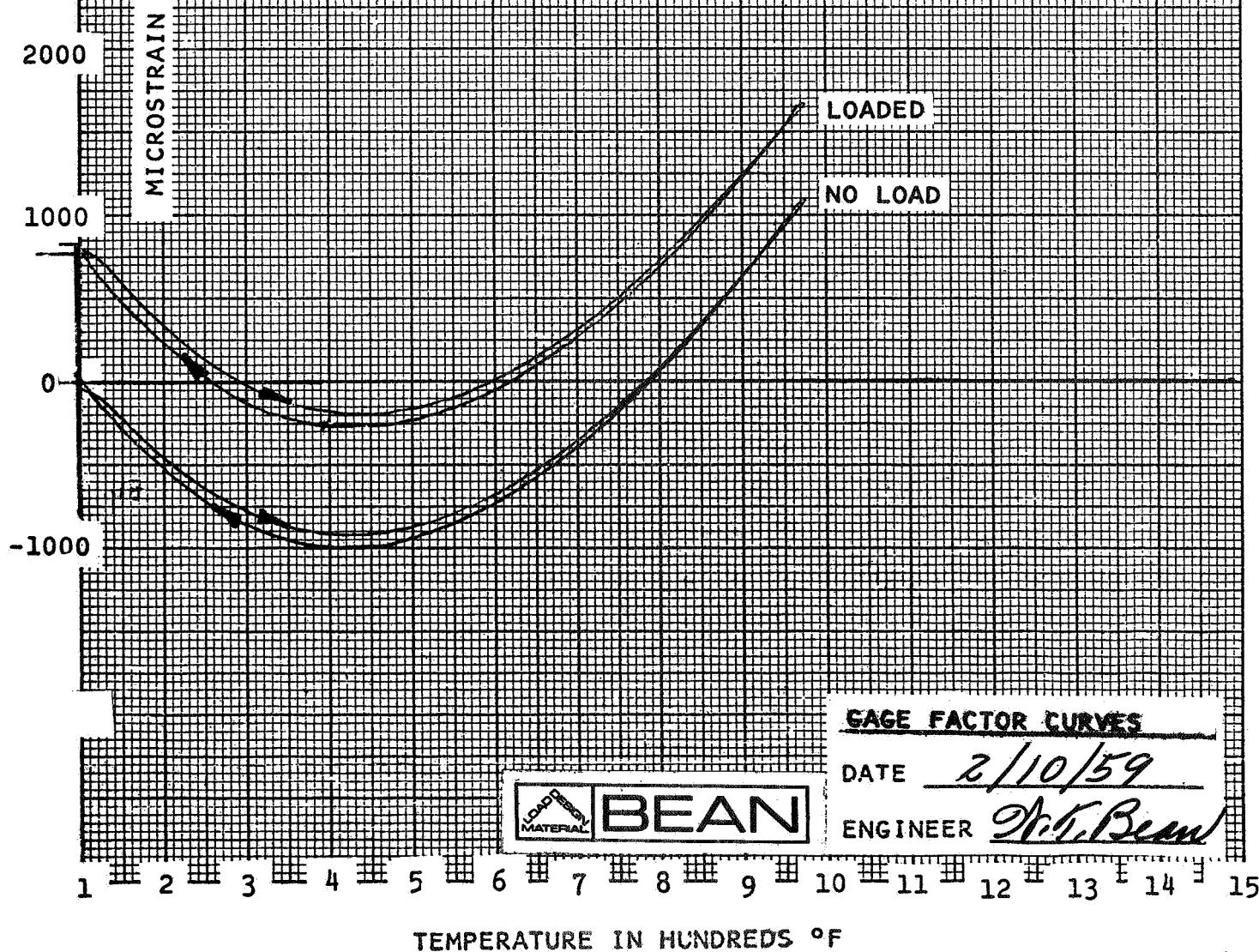
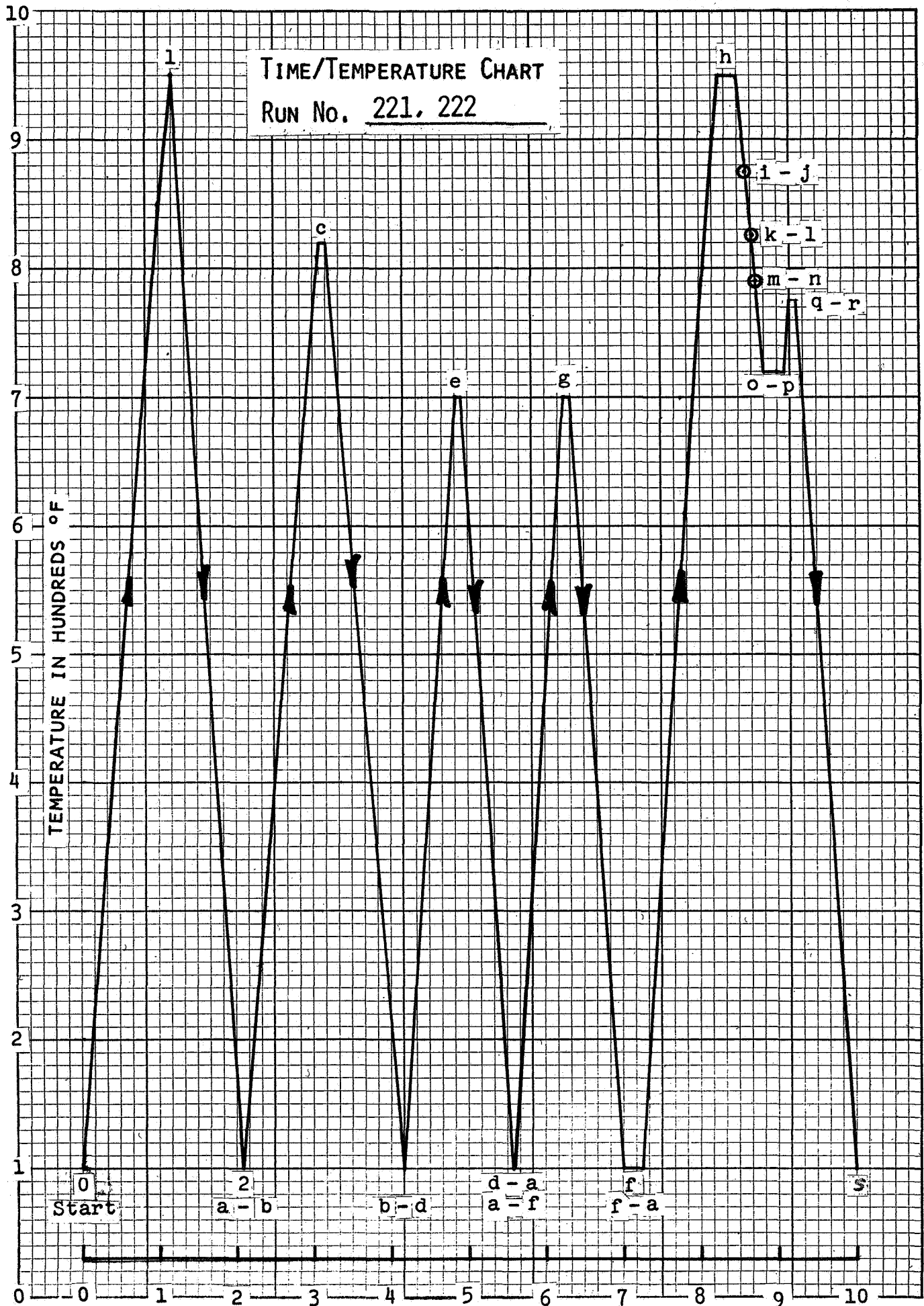


Table X

## RECORD OF TEST ON 17-4 PH FIXTURE

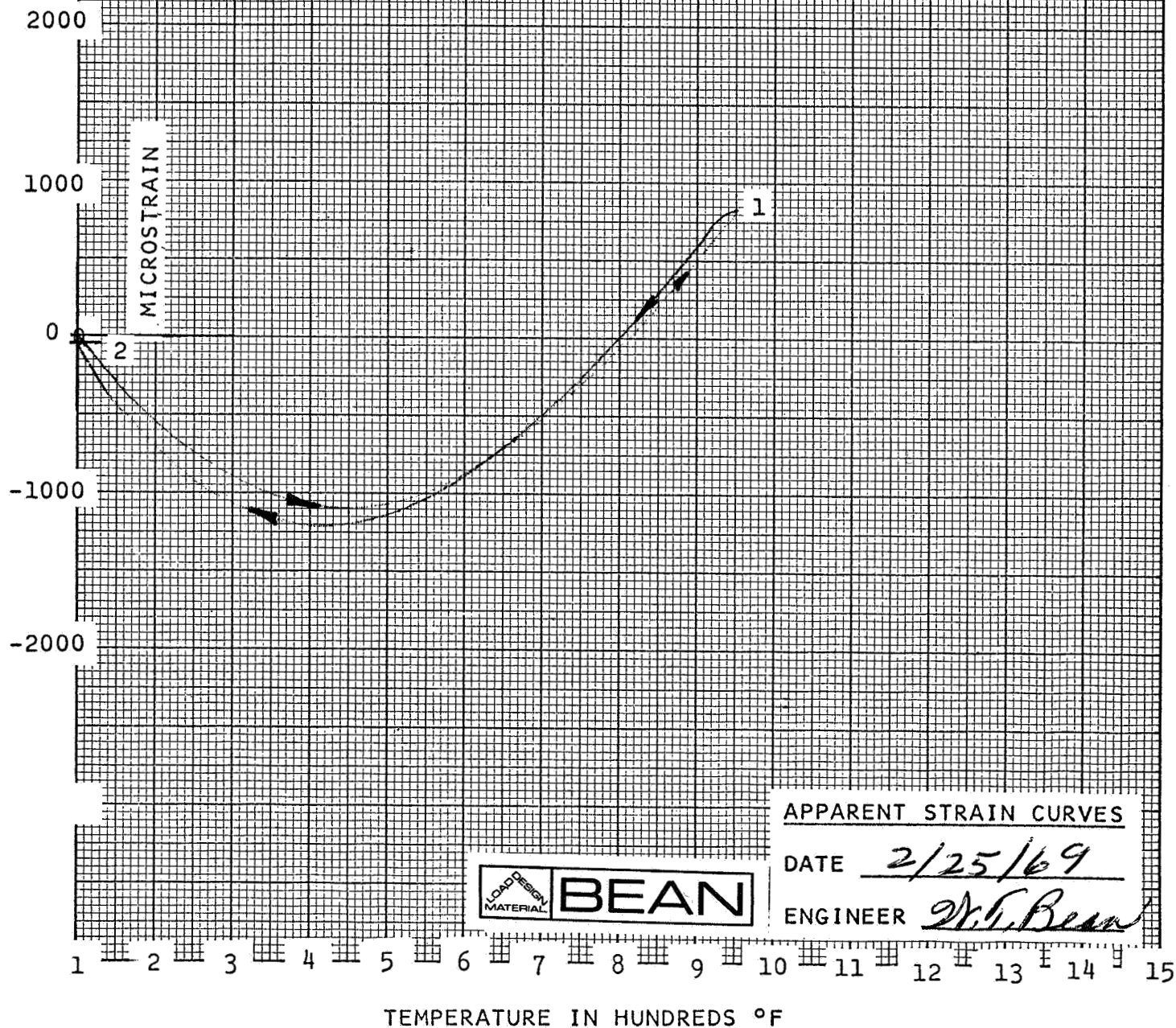
RUN NO. 221, 222

TEST EVENT	DESCRIPTION OF TEST	LAPSED TIME
0-1	Heat (100°F to 950°F) no load	1:10
1-2	Cool (950°F to 100°F) in air	2:05
a-b	Load (+870 $\mu\epsilon$ ) 100°F	2:06
b-c	Heat (100°F to 820°F) loaded	3:06
c-b	Cool (820°F to 100°F) loaded	4:11
b-d	Load (+1620 $\mu\epsilon$ ) 100°F	4:12
d-e	Heat (100°F to 700°F) loaded	4:52
e-d	Cool (700°F to 100°F) loaded	5:37
d-a	Unload at 100°F	5:38
a-f	Load (-2100 $\mu\epsilon$ ) 100°F	5:39
f-g	Heat (100°F to 700°F) loaded	6:15
g-f	Cool (700°F to 100°F) loaded	7:00
f-a	Unload at 100°F, standby	7:15
a-h	Heat (100°F to 950°F) no load	8:15
h-i	Cool (950°F to 875°F) no load	8:37
i-j	Load (+870 $\mu\epsilon$ ) 875°F	8:38
j-k	Cool (875°F to 825°F) loaded	8:40
k-l	Unload at 825°F	8:42
l-m	Cool (825°F to 790°F) no load	8:44
m-n	Load (+1620 $\mu\epsilon$ ) 790°F	8:45
n-o	Cool (790°F to 720°F) loaded	8:50
o-p	Load (-2100 $\mu\epsilon$ ) 720°F	8:51
p-q	Heat (720°F to 775°F) loaded	9:10
q-r	Unload at 775°F	9:11
r-s	Cool (775°F to 100°F) no load	10:00 hrs
a-s	Zero Offset (-30 $\mu\epsilon$ ) in 7:55 hrs	

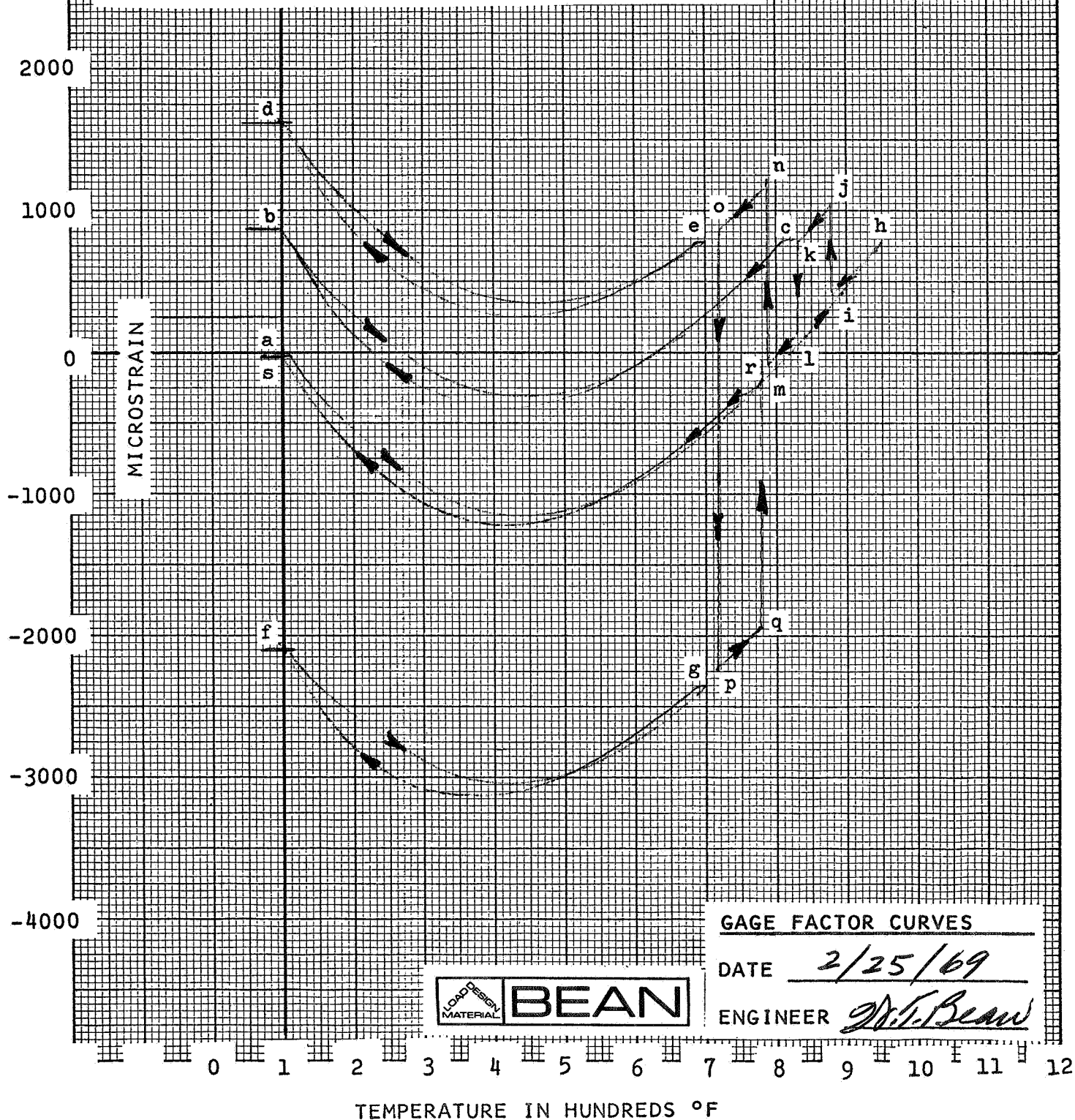




ALLOY #13/#3/HB RUN NO. 221  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL 17-4 PH (1/8")  
HEATING & COOLING RATE 10/20°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC



ALLOY #13/#3/HB RUN NO. 222  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL 17-4 PH (1/8")  
HEATING & COOLING RATE 10/20°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC



ALLOY #13/#3/HA RUN NO. 219  
ADHESIVE H-1 CURE 1 HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL 17-4 PH (1/8")  
HEATING & COOLING RATE 10/20°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

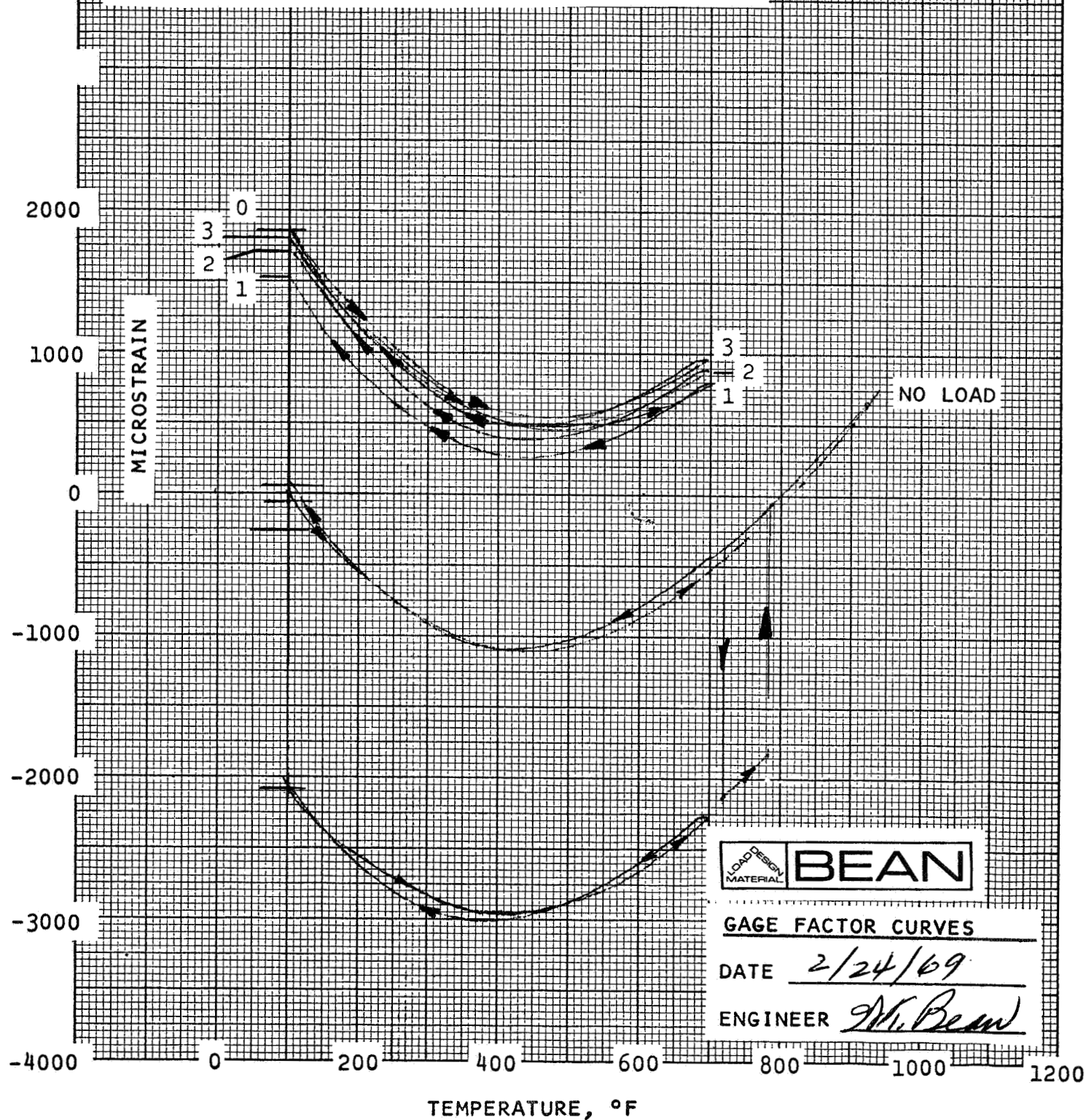


Table XI

## RECORD OF TEST ON J-1650 FIXTURE

RUN NO. 224, 225

TEST EVENT	DESCRIPTION OF TEST	LAPSED TIME
0-1	Load (+960 $\mu\epsilon$ ) 100°F	0:01
1-2	Heat (100°F to 1200°F) loaded	1:25
2-3	Cool (1200°F to 100°F) loaded	2:40
3-4	Unload at 100°F	2:41
4-5	Heat (100°F to 1200°F) no load	3:56
5-6	Load (+960 $\mu\epsilon$ ) 1200°F	3:57
6-5	Unload at 1200°F	3:58
5-7	Load (-815 $\mu\epsilon$ ) 1200°F	3:59
7-5	Unload at 1200°F	4:00
5-8	Cool (1200°F to 100°F) no load	5:10
8-0	Zero Offset (-700 $\mu\epsilon$ )	
8-8	New Chart (New Zero)	5:15
8-9	Heat (100°F to 1200°F) no load	7:00
9-10	Drift Check at 1200°F (15 min)	7:15
10-11	Drift Check at 1200°F (15 min)	7:30
11-12	Cool (1200°F to 100°F) no load	8:35 hrs
12- 8	Zero Offset (+50 $\mu\epsilon$ )	



Table XII

## RECORD OF TEST ON J-1650 FIXTURE

RUN NO. 226

TEST EVENT	DESCRIPTION OF TEST	LAPSED TIME
a	New chart (new Zero)	8:40
a-b	Load (+990 $\mu\epsilon$ ) 100°F	8:41
b-c	Load (-865 $\mu\epsilon$ ) 100°F	8:43
c-b	Load (+990 $\mu\epsilon$ ) 100°F	8:45
b-d	Heat (100°F to 1100°F) loaded	9:35
d-e	Cool (1100°F to 100°F) loaded	10:45
e-f	Unload "T" at 100°F	10:46
f-g	Load (-865 $\mu\epsilon$ ) 100°F	10:47
g-h	Heat (100°F to 1100°F) loaded	11:47
h-i	Cool (1100°F to 100°F) loaded	12:47
i-j	Unload "C" at 100°F	12:48
j-a	Reset Zero	12:49
a-b	Load (+990 $\mu\epsilon$ ) 100°F	12:50
b-d	Heat (100°F to 1100°F) loaded	13:50
d-e	Cool (1100°F to 100°F) loaded	15:05
e-f	Unload at 100°F "T" checks	15:06
f-g	Load (-865 $\mu\epsilon$ ) 100°F	15:07
g-h	Heat (100°F to 1100°F) loaded	15:57
h-i	Cool (1100°F to 100°F) loaded	17:02
i-j	Unload at 100°F "C" checks	17:03
j-a	Reset Zero	17:04
a-k	Heat (100°F to 1175°F) no load	18:29
k-l	Load (-815 $\mu\epsilon$ ) 1175°F	18:30
l-m	Heat (1175°F to 1190°F) loaded	18:33
m-n	Unload at 1190°F	18:34
n-o	Heat (1190°F to 1210°F) no load	18:38
o-p	Load (+960 $\mu\epsilon$ ) 1210°F	18:39
p-q	Cool (1210°F to 1150°F) loaded	18:49
q-r	Load (+960 $\mu\epsilon$ to -815 $\mu\epsilon$ ) 1150°F	18:50
r-s	Cool (1150°F to 1125°F) loaded	18:52
s-t	Load (-815 $\mu\epsilon$ to +960 $\mu\epsilon$ ) 1125°F	18:53
t-d	Cool (1125°F to 1100°F) loaded	18:55
d-u	Unload at 1100°F	18:56
u-f	Cool (1100°F to 100°F)	19:58 hrs

# TIME/TEMPERATURE CHART

Run No 224, 225, 226

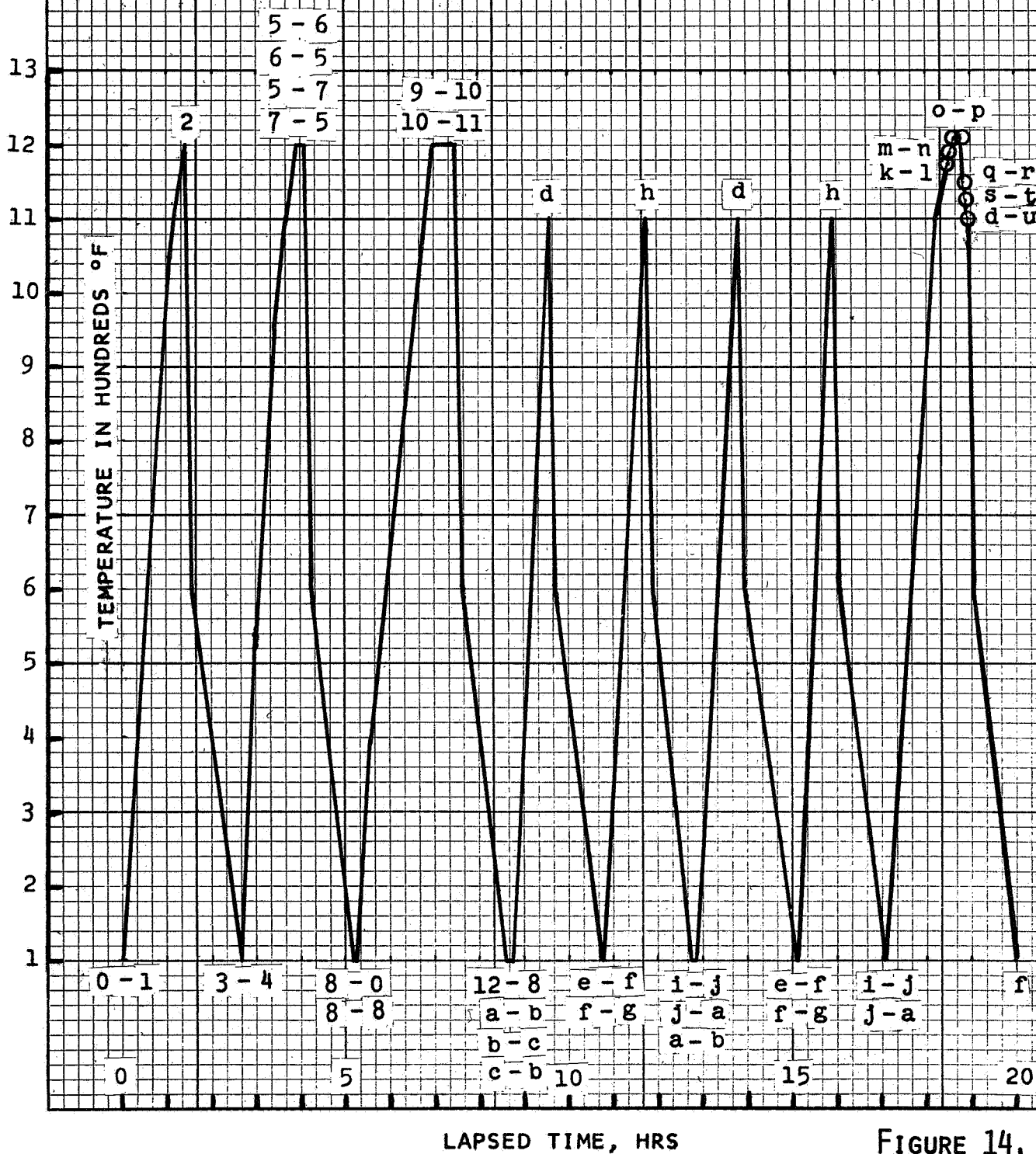
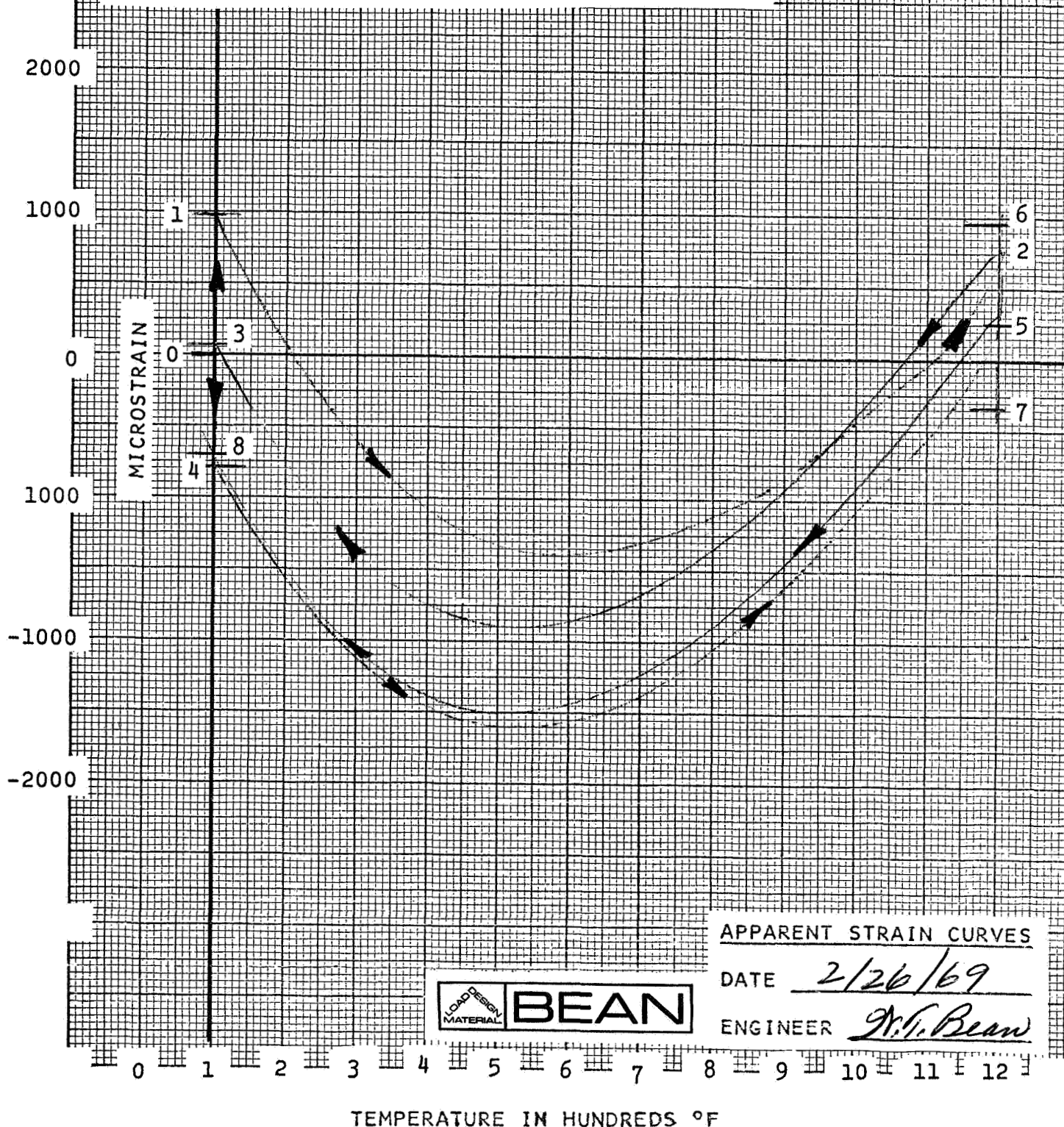
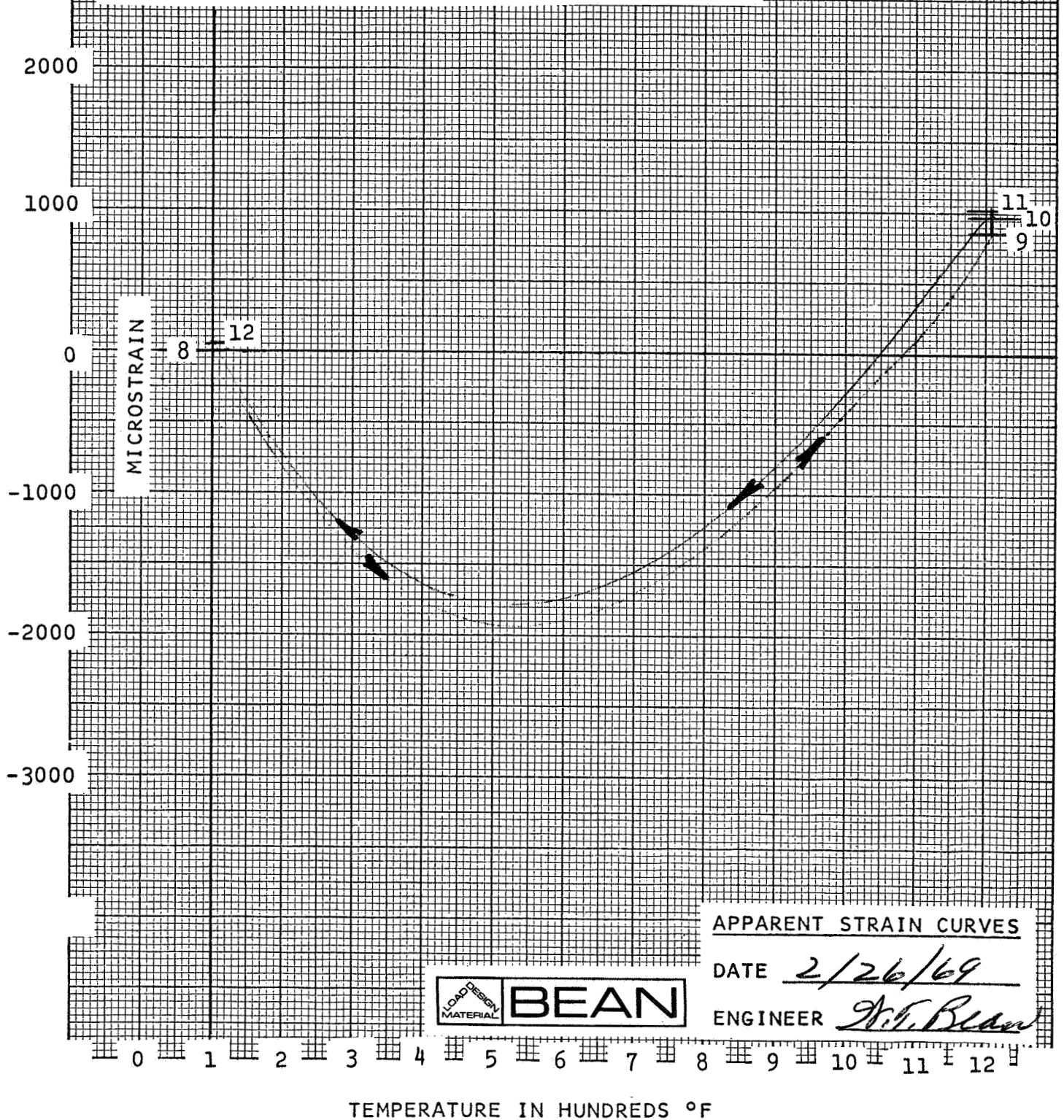


FIGURE 14.

ALLOY #13/#3/4B RUN NO. 224  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL J-1650 (1/8")  
HEATING & COOLING RATE 20/60°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

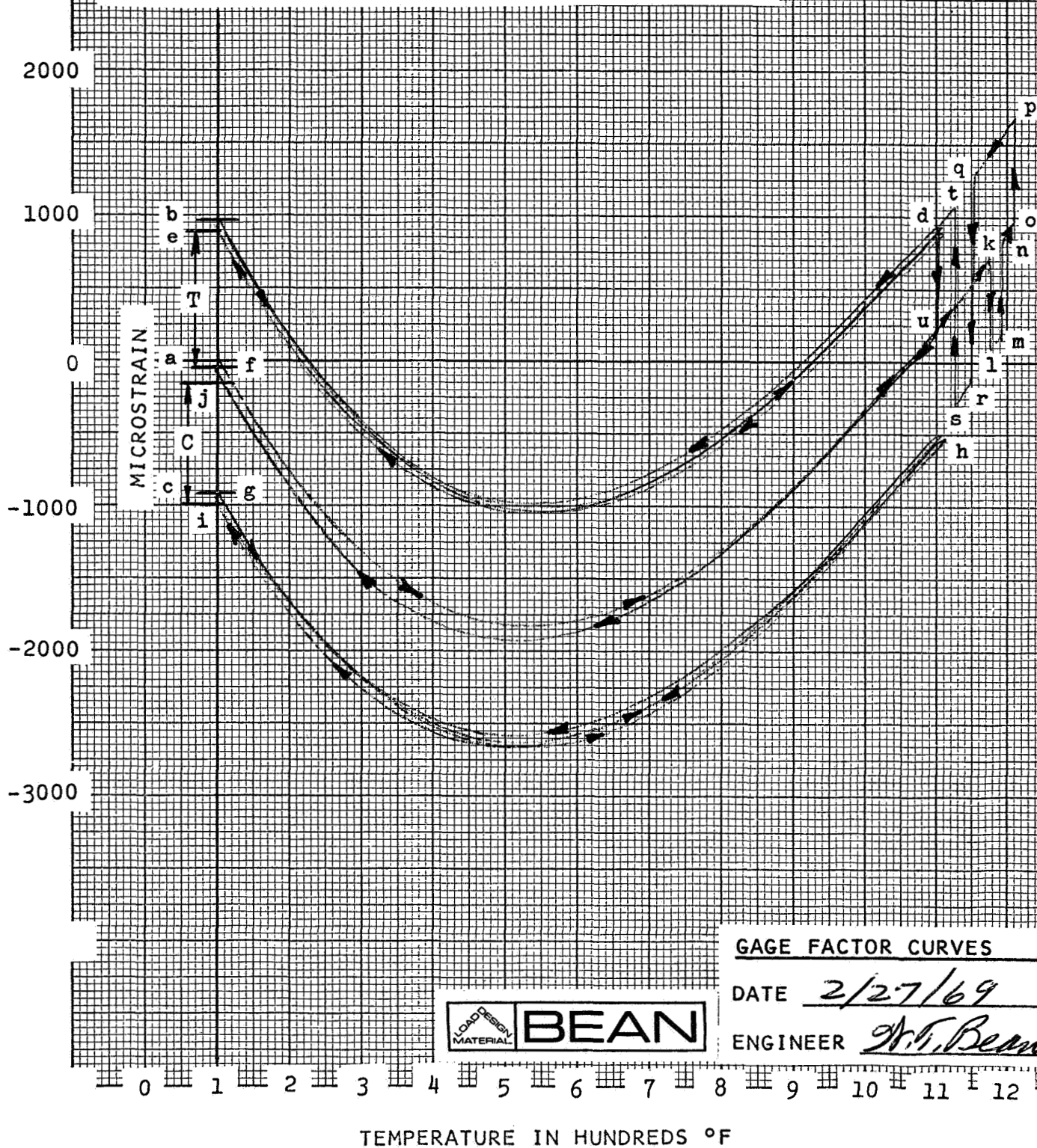


ALLOY #13/#3/HB RUN NO. 225  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL J-1650 (1/8")  
HEATING & COOLING RATE 20/60°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC





ALLOY #13/#3/HB RUN NO. 226  
ADHESIVE H-1 CURE 1HR@600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL J-1650 (1/8")  
HEATING & COOLING RATE 20/60°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC



# GAGE FACTOR VS TEMPERATURE

ALLOY #13/#3

## CONSTANT TEMPERATURE DATA (POINT BY POINT)

- + 17-4PH 1/4" FIXTURE 2/10/69
- X J-1650 1/8" FIXTURE 2/12/69
- J-1650 1/8" FIXTURE 2/27/69

## TRANSIENT TEMPERATURE RUNS (TC CURVES)

- RUN 201 2/10/69
- ▽ RUN 222 2/25/69
- ◻ RUN 226 2/26/69

PERCENT OF GAGE FACTOR @ 100°F

100  
98  
96  
94  
92  
90  
88  
86  
84  
82  
80  
78  
76  
74  
72  
70

0

1

2

3

4

5

6

7

8

9

10

11

12

TEMPERATURE IN HUNDREDS °F

FIGURE 15.

LOAD DESIGN  
MATERIAL

BEAN

ALLOY #13/#3 RUN NO. 144  
ADHESIVE H CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 10/10°F/MIN  
BRIDGE EXCITATION 2.5 DC VOLTS  
TEMPERATURE SENSOR C/A TC

RESISTANCE OF GAGES @ 100°F  
(2 MIL WIRE)

#1 ACTIVE ELEMENT = 59.34  $\Omega$   
COMP. ELEMENT = 19.96  $\Omega$   
DUMMY RESISTOR = 39.38  $\Omega$

#2 ACTIVE ELEMENT = 59.35  $\Omega$   
COMP. ELEMENT = 19.97  $\Omega$   
DUMMY RESISTOR = 39.38  $\Omega$

GAGE FACTOR @ 3.23

3000

MICROSTRAIN

2000

1000

-1000

-2000

APPARENT STRAIN CURVES

DATE 11/23/68

ENGINEER H. F. Bean



BEAN

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

TEMPERATURE IN HUNDREDS °F

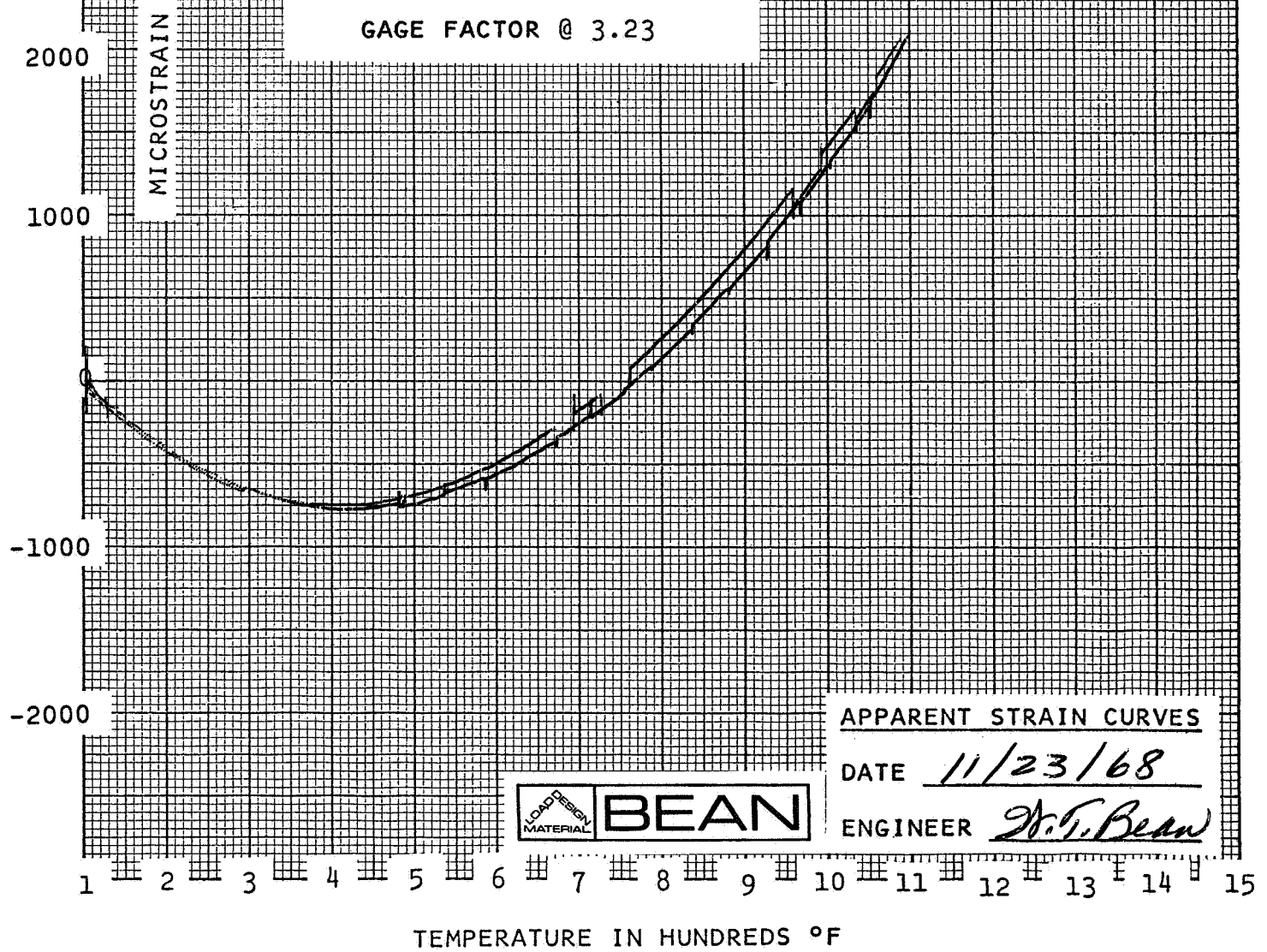


ALLOY #13/#3 RUN NO. 145  
ADHESIVE H CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 10/10°F/MIN  
BRIDGE EXCITATION 2.5 DC VOLTS  
TEMPERATURE SENSOR C/A TC

RESISTANCE OF GAGES @ 100°F  
(2 MIL WIRE)

#1 ACTIVE ELEMENT = 59.34  $\Omega$   
COMP. ELEMENT = 19.96  $\Omega$   
DUMMY RESISTOR = 39.38  $\Omega$   
#2 ACTIVE ELEMENT = 59.35  $\Omega$   
COMP. ELEMENT = 19.97  $\Omega$   
DUMMY RESISTOR = 39.38  $\Omega$

GAGE FACTOR @ 3.23



APPARENT STRAIN CURVES

DATE 11/23/68

ENGINEER J. F. Bean





ALLOY #13/#3 RUN NO. 146  
ADHESIVE 14 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 10/10°F/MIN  
BRIDGE EXCITATION 2.5 DC VOLTS  
TEMPERATURE SENSOR C/A TC

TWO ACTIVE GAGES  
(BACK TO BACK IN BENDING)

POINTS ARE TAKEN FROM  
GAGE FACTOR VS TEMPERATURE CURVE

3000

2500

2000

1500

1000

500

-500

MICROSTRAIN

LOAD DESIGN  
MATERIAL

BEAN

GAGE FACTOR CURVES

DATE 11/24/68

ENGINEER W.F. Beal

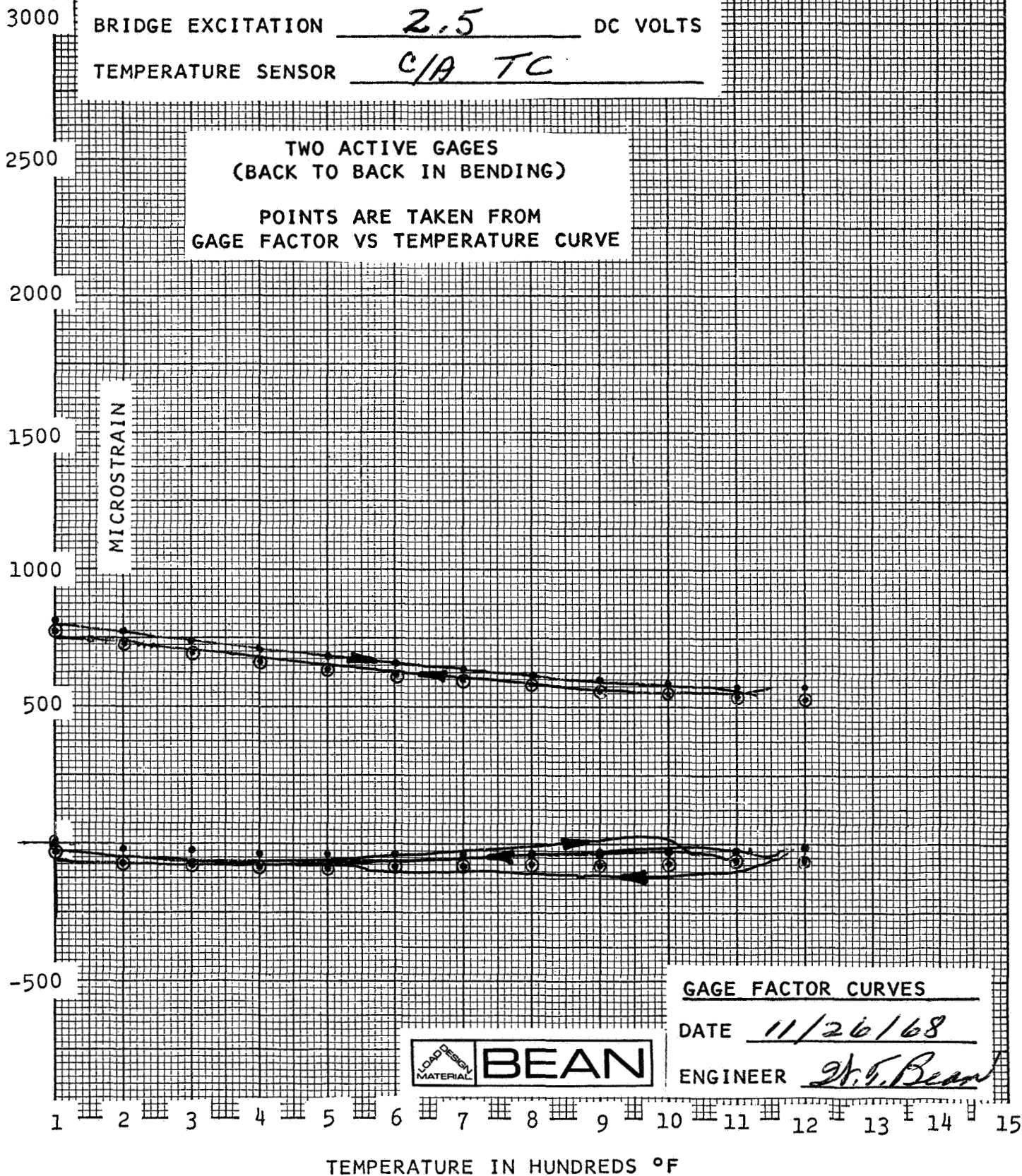
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

TEMPERATURE IN HUNDREDS °F

ALLOY #13/#3 RUN NO. 147  
ADHESIVE H CURE 1hr @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 10/10°F/MIN  
BRIDGE EXCITATION 2.5 DC VOLTS  
TEMPERATURE SENSOR C/A TC

TWO ACTIVE GAGES  
(BACK TO BACK IN BENDING)

POINTS ARE TAKEN FROM  
GAGE FACTOR VS TEMPERATURE CURVE



### Heating and Cooling Rates

The Alloy #13/#3 gage was evaluated under various heating and cooling rates (Figures 16 and 17). Heating rates up to 1000°F per minute were employed (Runs # 231 and # 232).

# TYPICAL HEATING & COOLING RATES

## USED IN STRAIN GAGE ALLOY EVALUATION

CURVE A--NORMAL HEATING & COOLING (H/C) RATE OF OVEN

CURVE B--COOLING RATE OF 1/4X1-1/4X9" SPECIMEN IN AIR

CURVE C--MAXIMUM H/C RATE FOR 1/4X1-1/4X9" SPECIMEN  
(PREHEATED OVEN/AIR JET)

CURVE D--MAXIMUM H/C RATE FOR 1/16X1X6" SPECIMEN  
(PREHEATED OVEN/AIR JET)

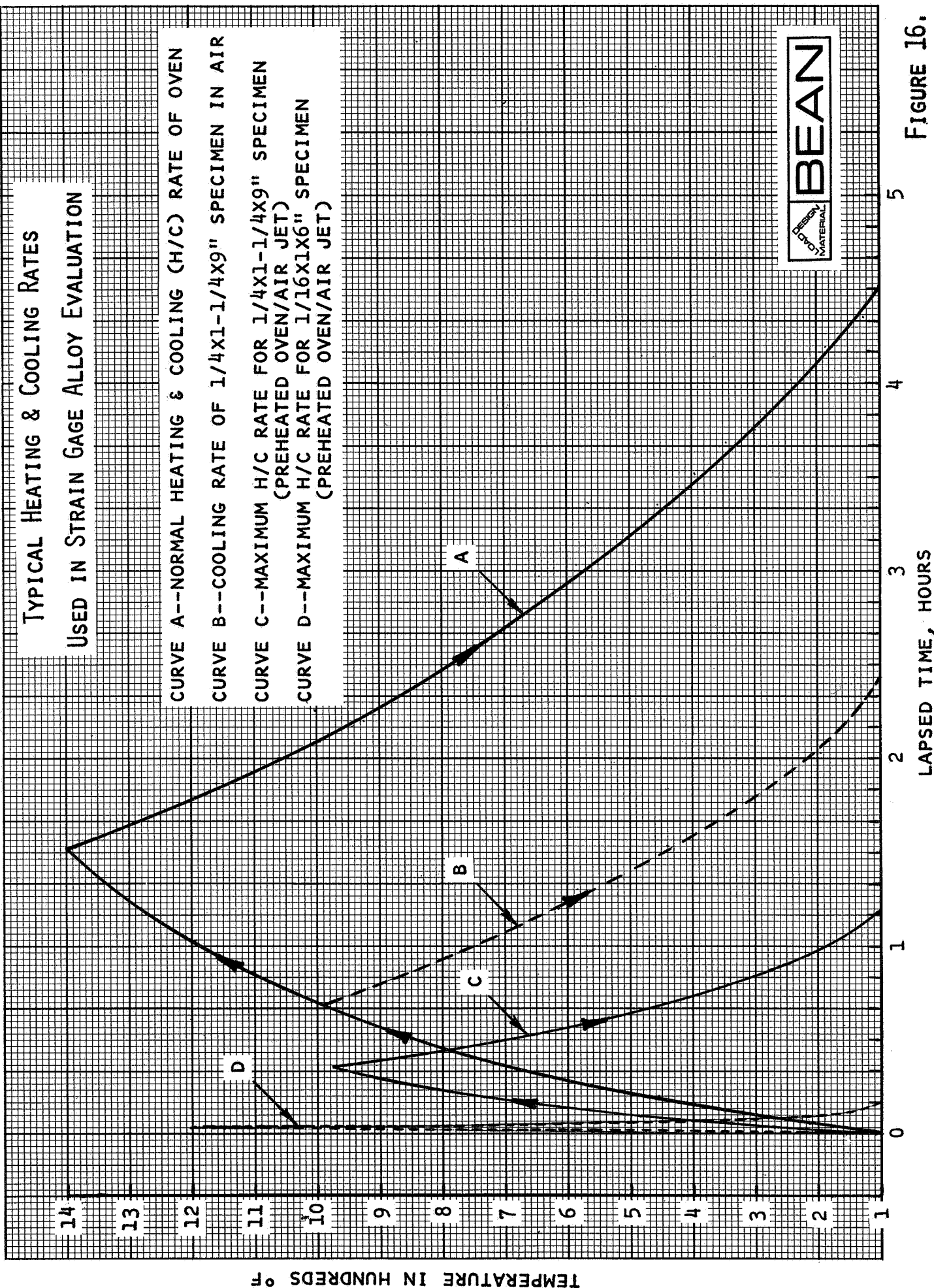


FIGURE 16.



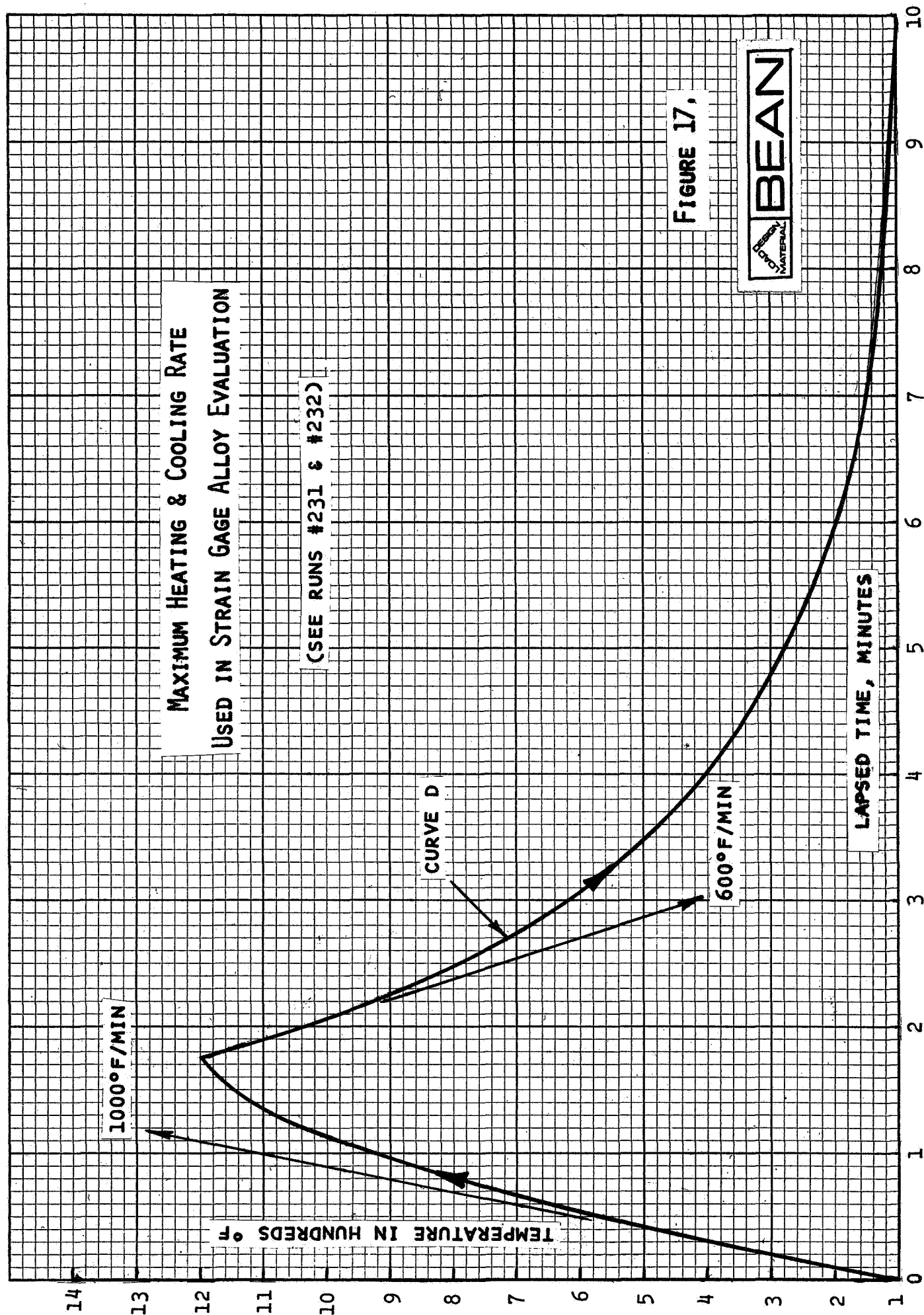


FIGURE 17.

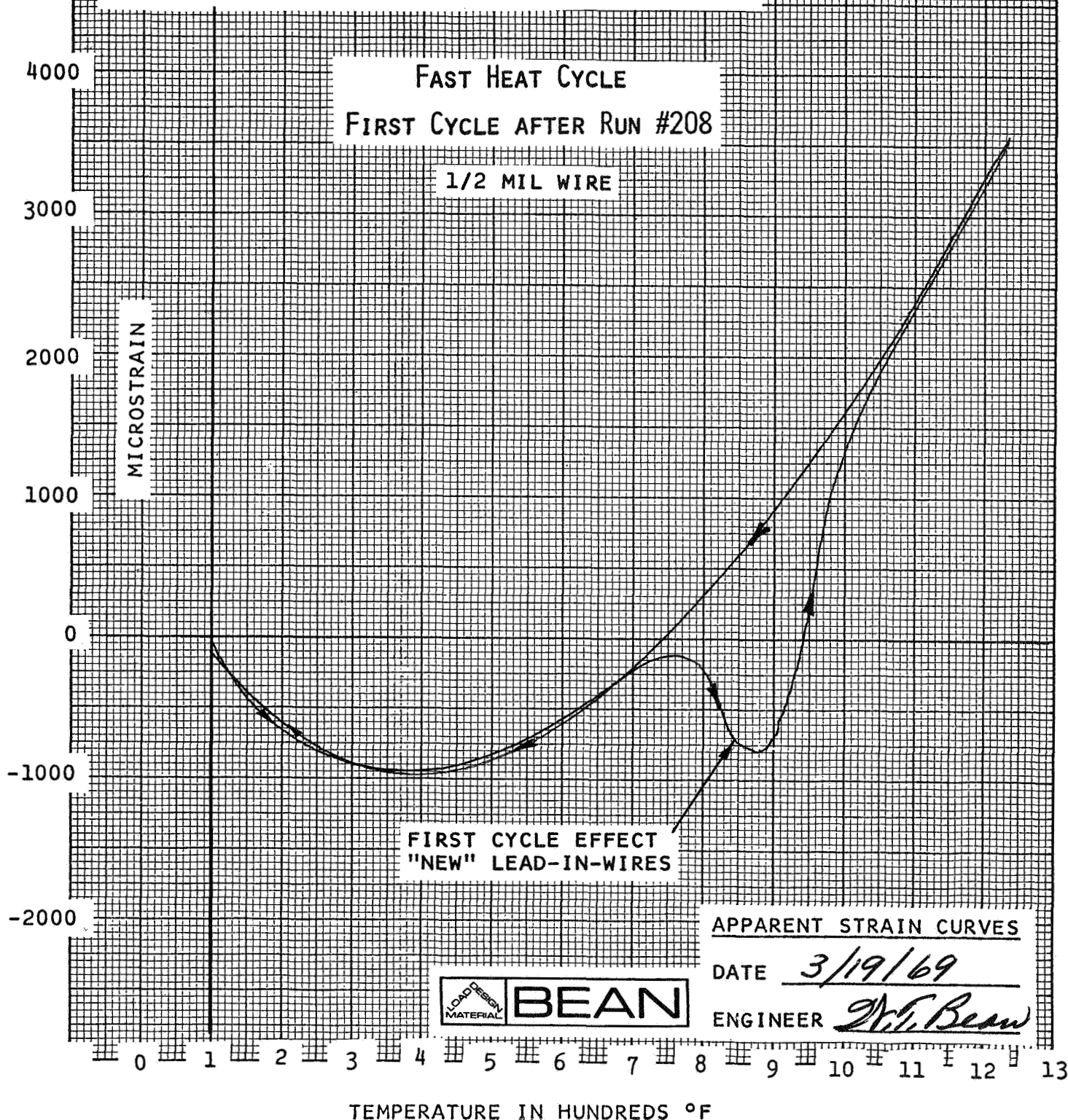


ALLOY #13/#3/40 RUN NO. 231  
ADHESIVE H-1 CURE 1HR@600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X (1/16")  
HEATING & COOLING RATE 1000/600°F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC

FAST HEAT CYCLE  
FIRST CYCLE AFTER RUN #208

1/2 MIL WIRE

MICROSTRAIN



FIRST CYCLE EFFECT  
"NEW" LEAD-IN WIRES

APPARENT STRAIN CURVES

DATE 3/19/69

ENGINEER A.E. Bean

LOAD DESIGN MATERIAL **BEAN**

TEMPERATURE IN HUNDREDS °F

ALLOY #13/#3/H0 RUN NO. 232

ADHESIVE H-1 CURE 1HR@600°F

CLAMP PRESSURE NO POST CURE NO

SPECIMEN MATERIAL HASTELLOY-X (1/16")

HEATING & COOLING RATE 1000/600°F/MIN

BRIDGE EXCITATION 6.4 DC VOLTS

TEMPERATURE SENSOR C/A TC

4000

3000

2000

1000

MICROSTRAIN

0

-1000

-2000

FAST HEAT CYCLE  
FIRST CYCLE AFTER RUN #231

1/2 MIL WIRE

APPARENT STRAIN CURVES

DATE 3/19/69

ENGINEER W. J. Bean

LOAD DESIGN MATERIAL **BEAN**

0 1 2 3 4 5 6 7 8 9 10 11 12 13

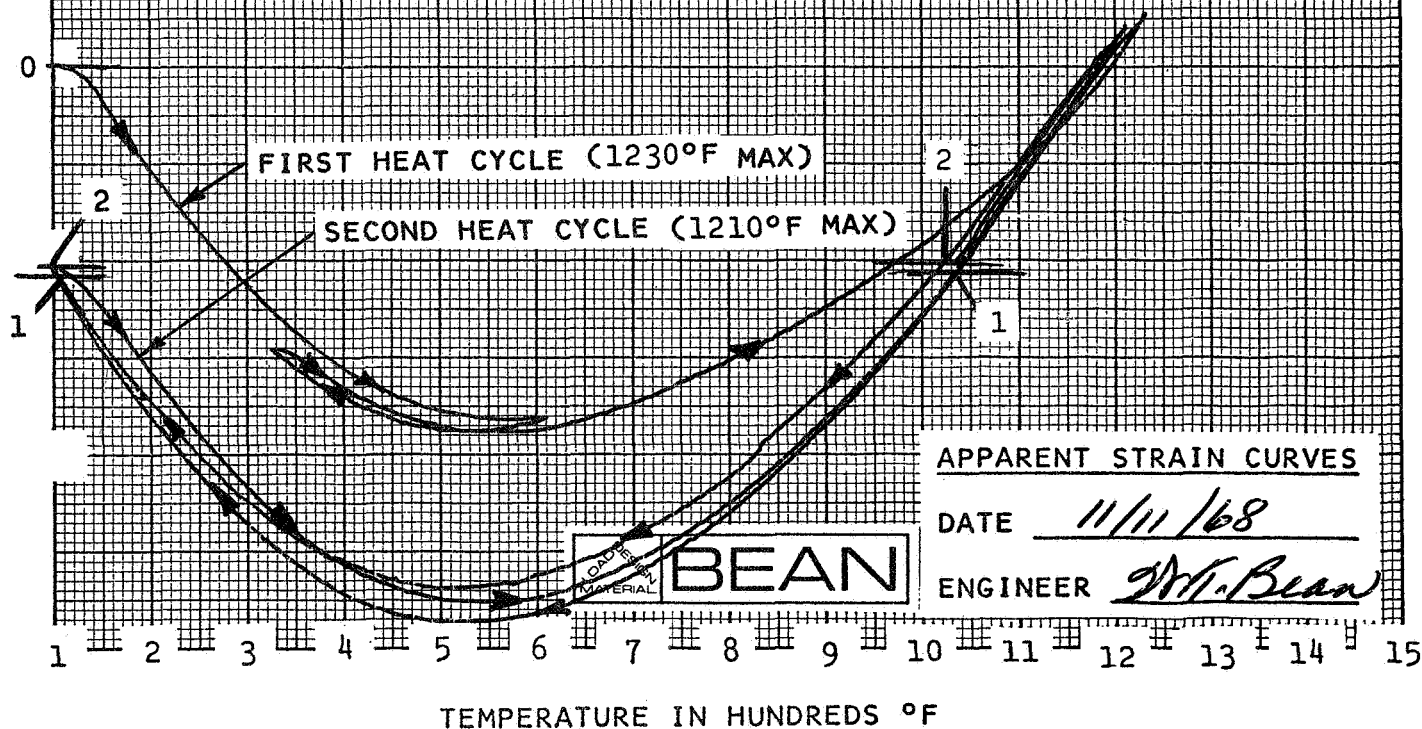
TEMPERATURE IN HUNDREDS °F

### Stability

Runs # 127 through # 130 show the results of stability tests conducted on an Alloy #13/#3 strain gage. Run # 130 logged twelve hours at 1200°F. Drift at 1200°F (as well as zero offset) vs. time is indicated. Runs # 139 and # 140 show stability tests conducted on a second specimen.

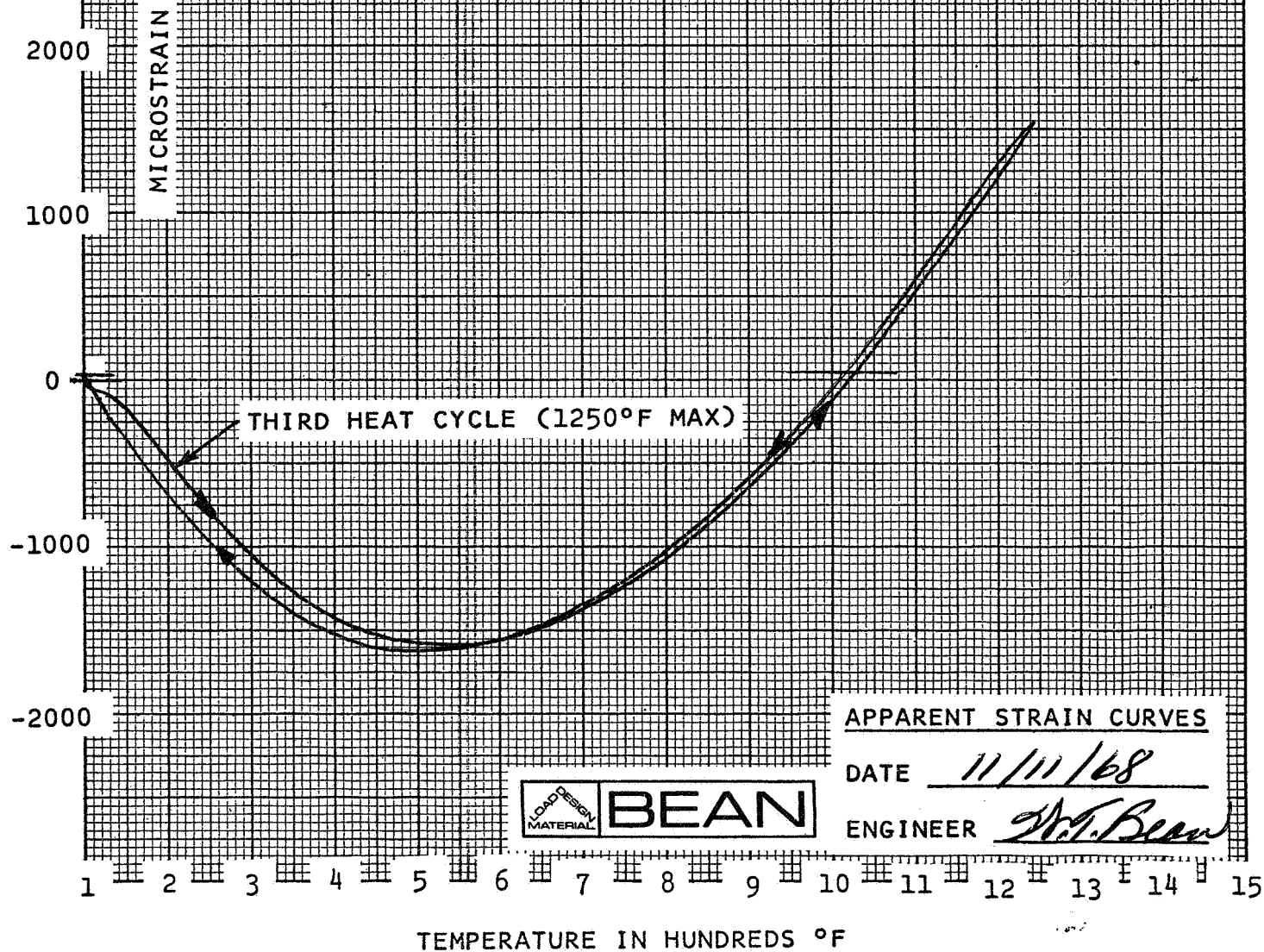
Runs # 141, # 142, # 143 show test results on a third specimen. Run # 208 was made with a strain gage employing 1/2 mil diameter wire. Figure 18 summarizes drift data.





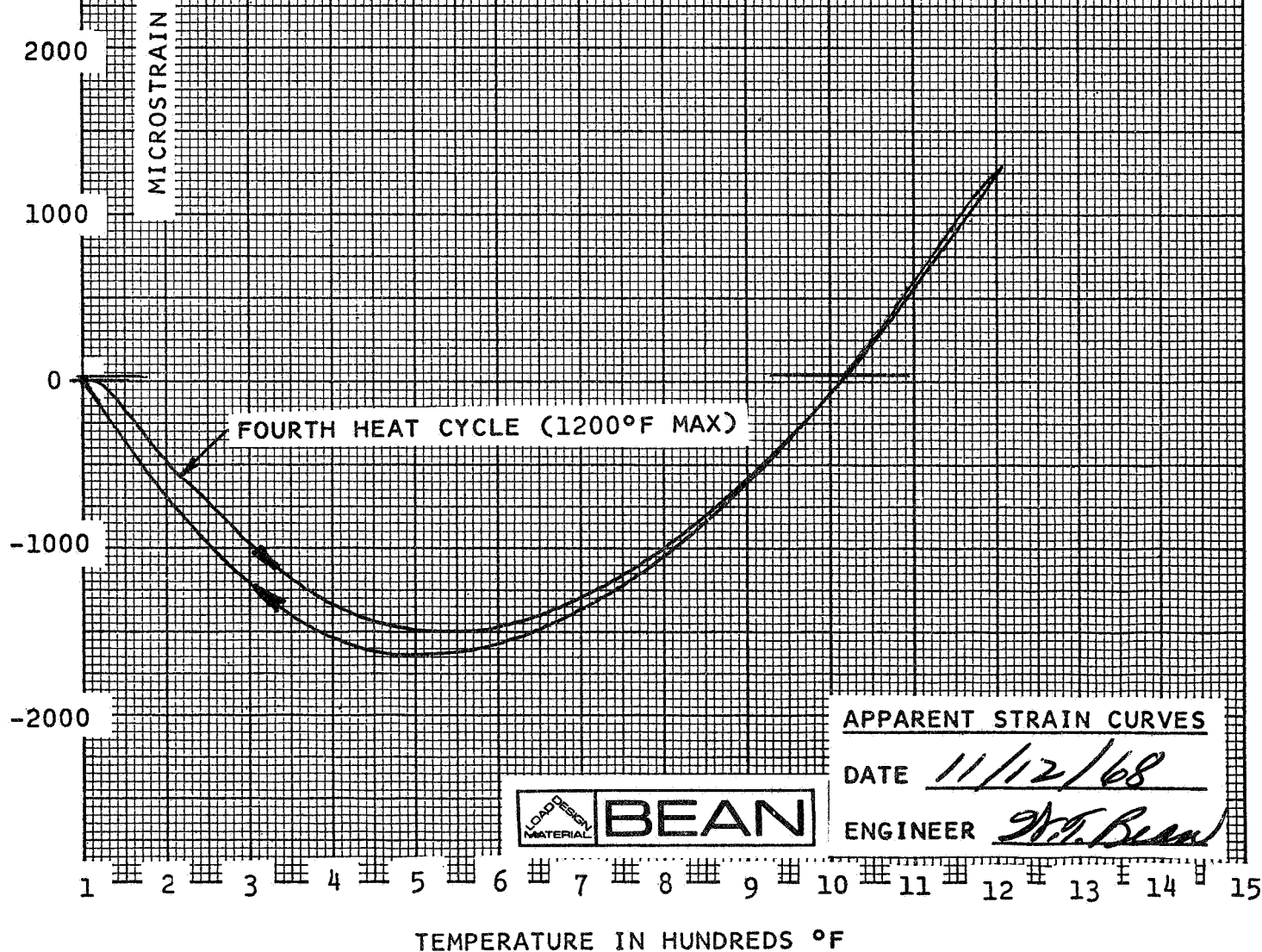
ALLOY #13/#3 RUN NO. 128  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 1.5 DC VOLTS  
TEMPERATURE SENSOR C/A TC

SAME SPECIMEN & GAGE AS RUN #127



ALLOY #13/#3 RUN NO. 129  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 1.5 DC VOLTS  
TEMPERATURE SENSOR C/A TC

SAME SPECIMEN & GAGE AS RUN #127

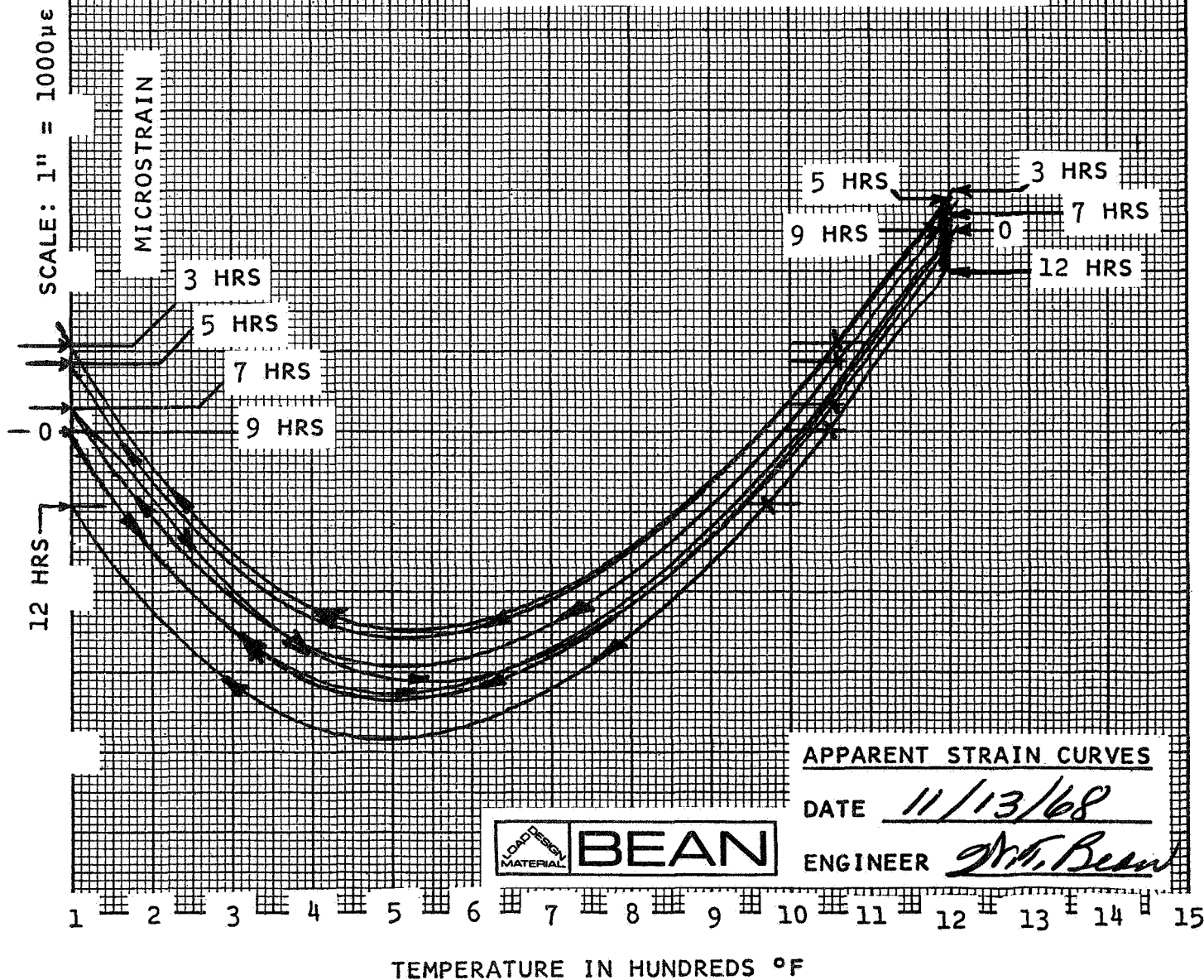


ALLOY #13/#3 RUN NO. 130  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 1.5 DC VOLTS  
TEMPERATURE SENSOR C/A TC

SAME SPECIMEN & GAGE AS RUN #127

DRIFT VS TIME

AFTER FIFTH HEAT CYCLE (1200°F MAX)





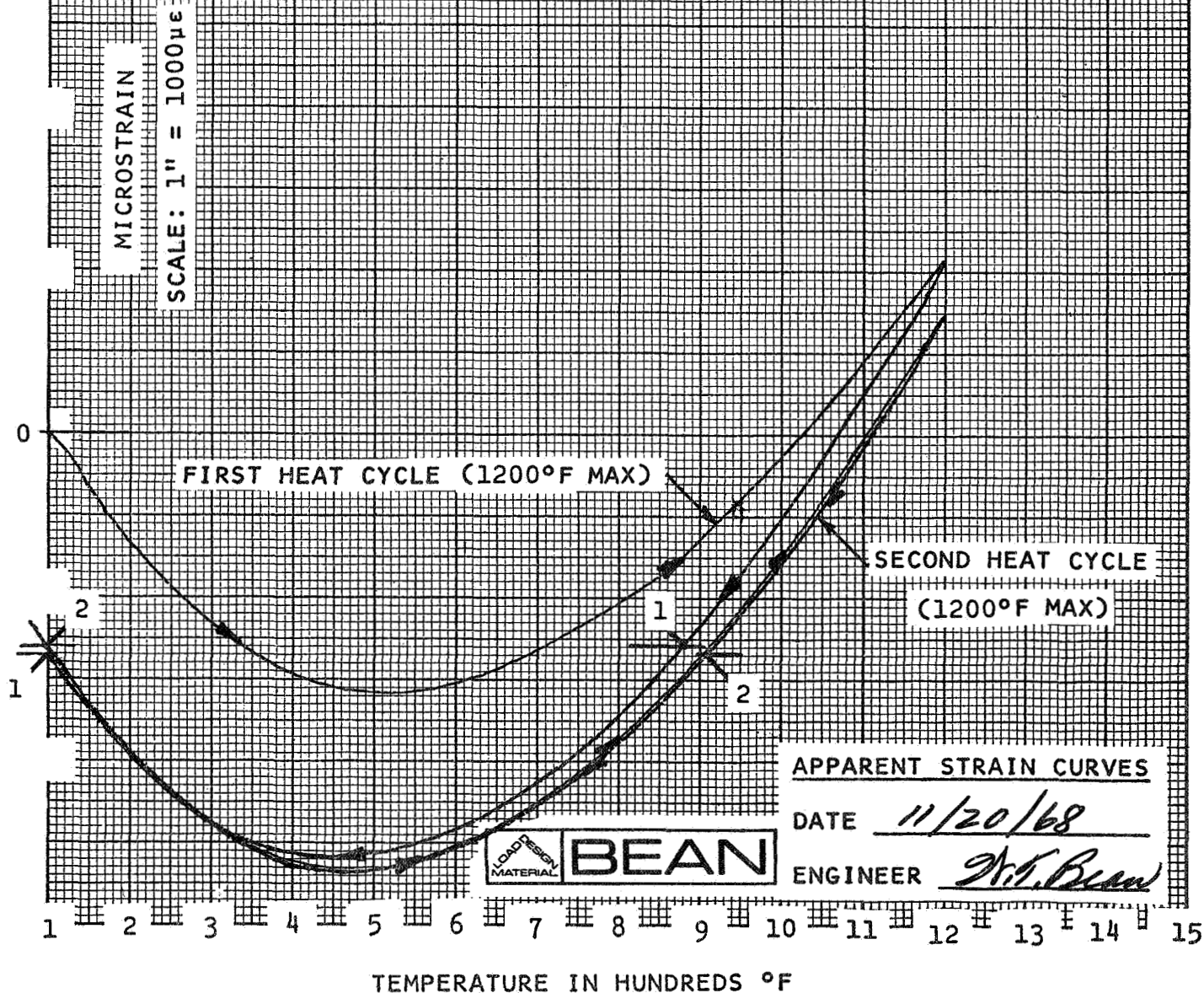
ALLOY #13/#3 RUN NO. 139  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 1.5 DC VOLTS  
TEMPERATURE SENSOR C/A TC

2 MIL WIRE

$R_{13} = 60\Omega$

$R_3 = 20\Omega$

BARE WIRE STABILIZED 30 MIN @ 1250°F TO 1275°F



ALLOY #13/#3 RUN NO. 140  
 ADHESIVE H-1 CURE 1HR @ 600°F  
 CLAMP PRESSURE No POST CURE No  
 SPECIMEN MATERIAL HASTELLOY-X  
 HEATING & COOLING RATE 20/20°F/MIN  
 BRIDGE EXCITATION 1.5 DC VOLTS  
 TEMPERATURE SENSOR C/A TC

SAME SPECIMEN & GAGE AS RUN #139

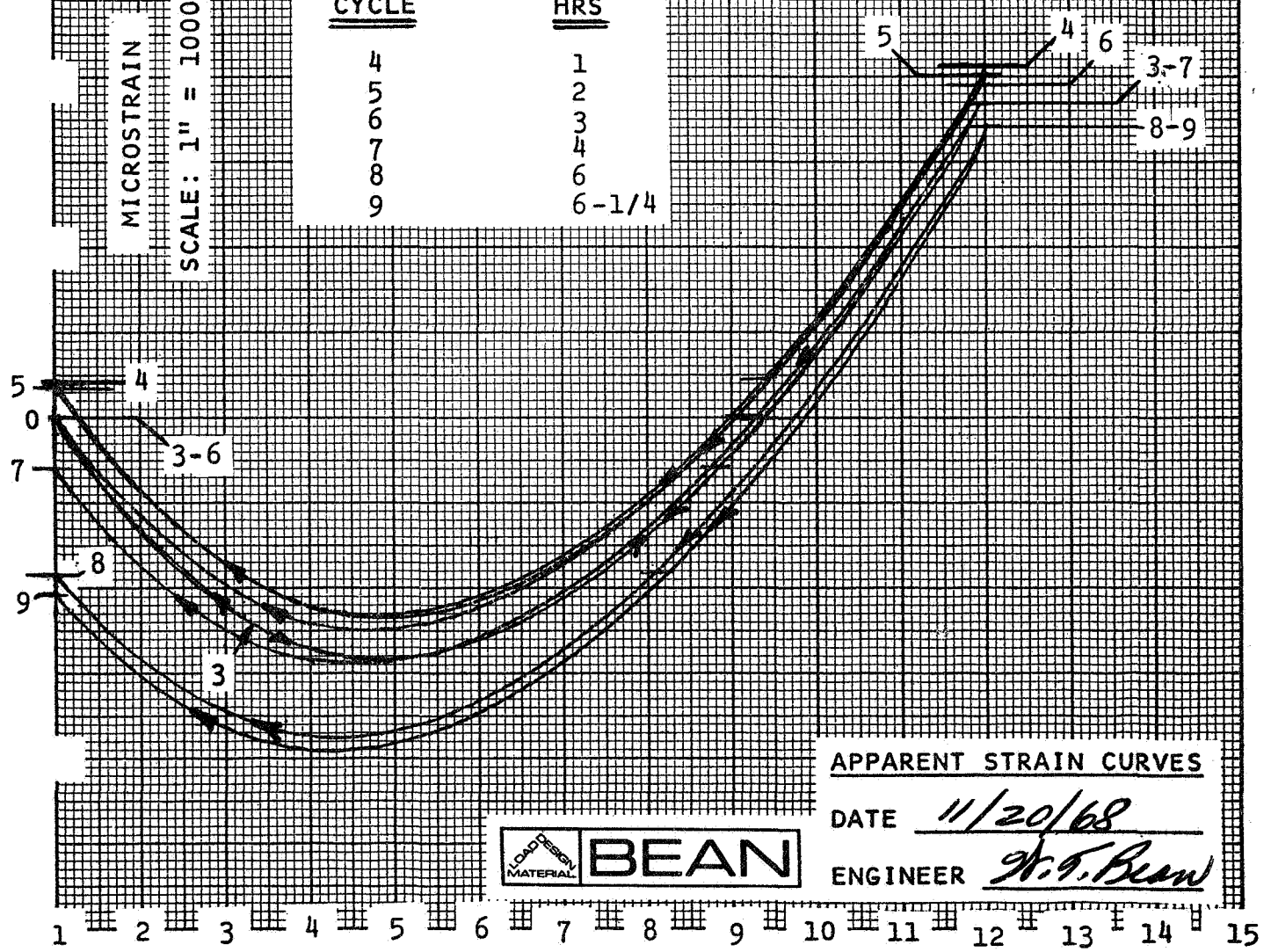
COOLING CYCLES 3-9 AS INDICATED

LAPSED TIME @ 1200°F

<u>CYCLE</u>	<u>HRS</u>
4	1
5	2
6	3
7	4
8	6
9	6-1/4

MICROSTRAIN

SCALE: 1" = 1000µε



APPARENT STRAIN CURVES

DATE 11/20/68  
 ENGINEER H. F. Bean



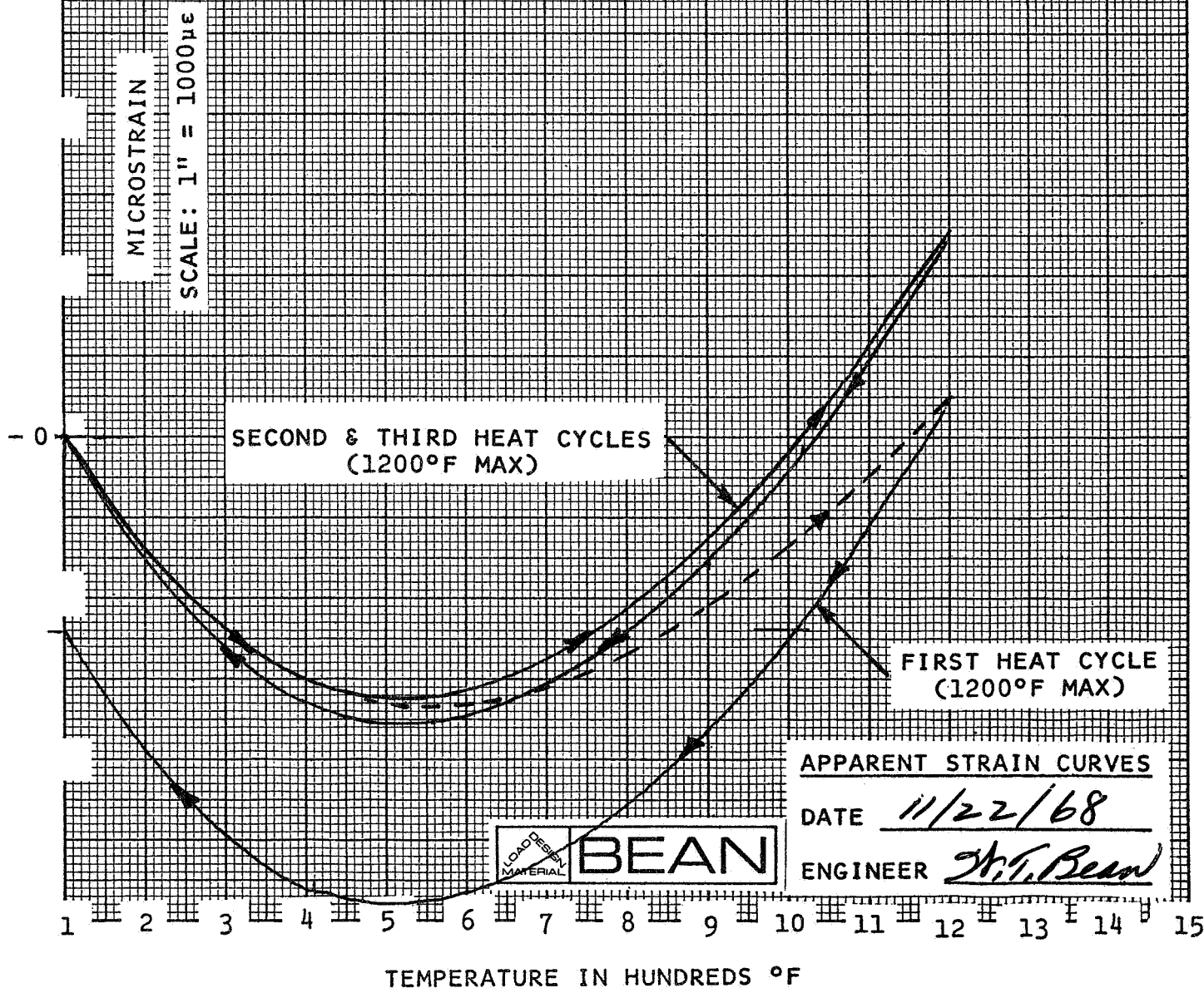
ALLOY #13/#3 RUN NO. 141  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 1.5 DC VOLTS  
TEMPERATURE SENSOR C/A TC

2 MIL WIRE

$R_{13} = 60\Omega$

$R_3 = 20\Omega$

BARE WIRE STABILIZED 30 MIN @ 1275°F TO 1300°F





ALLOY #13/#3 RUN NO. 142  
ADHESIVE H-1 CURE 1HR @ 600°F  
CLAMP PRESSURE NO POST CURE NO  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 1.5 DC VOLTS  
TEMPERATURE SENSOR C/A TC

SAME SPECIMEN & GAGE AS RUN #141

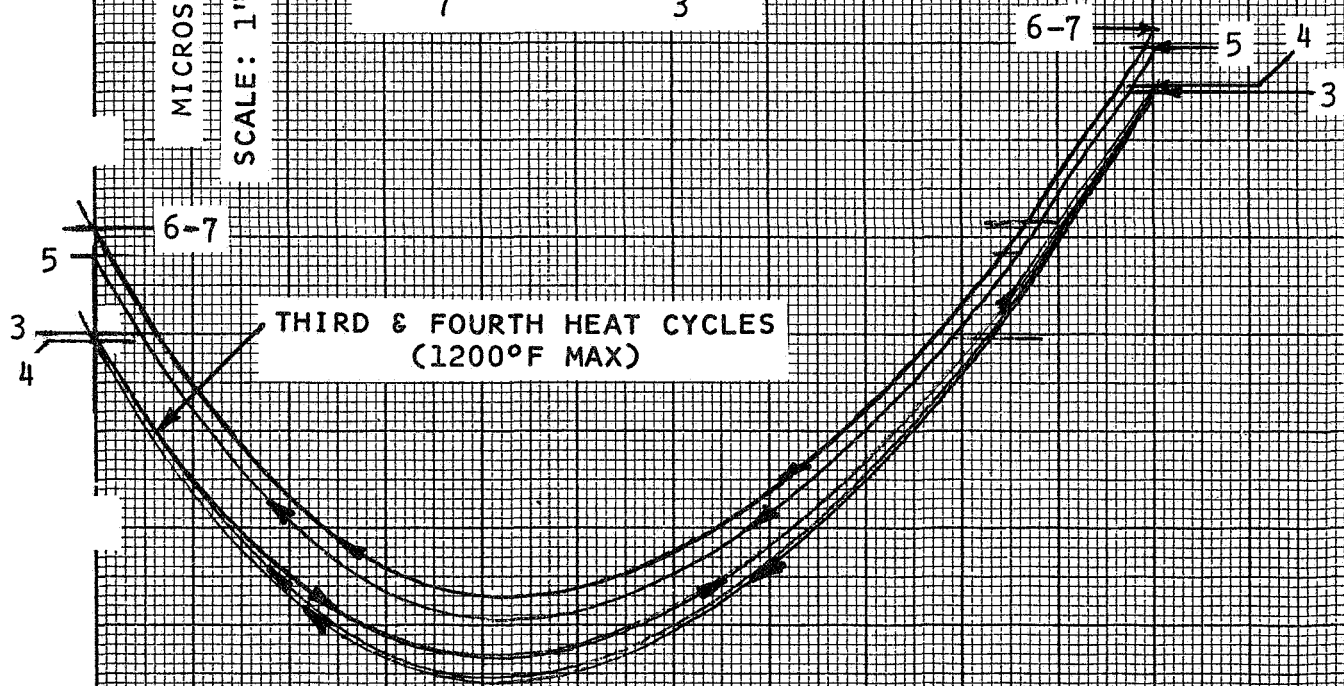
COOLING CYCLES 5-7 AS INDICATED

LAPSED TIME @ 1200°F

<u>CYCLE</u>	<u>HRS</u>
5	1
6	2
7	3

MICROSTRAIN

SCALE: 1" = 1000 $\mu$ e



APPARENT STRAIN CURVES

DATE 11/23/68

ENGINEER Dr. T. Bean



TEMPERATURE IN HUNDREDS °F



ALLOY #13/#3 RUN NO. 143  
ADHESIVE H-1 CURE 1HR@600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X  
HEATING & COOLING RATE 20/20°F/MIN  
BRIDGE EXCITATION 1.5 DC VOLTS  
TEMPERATURE SENSOR C/A TC

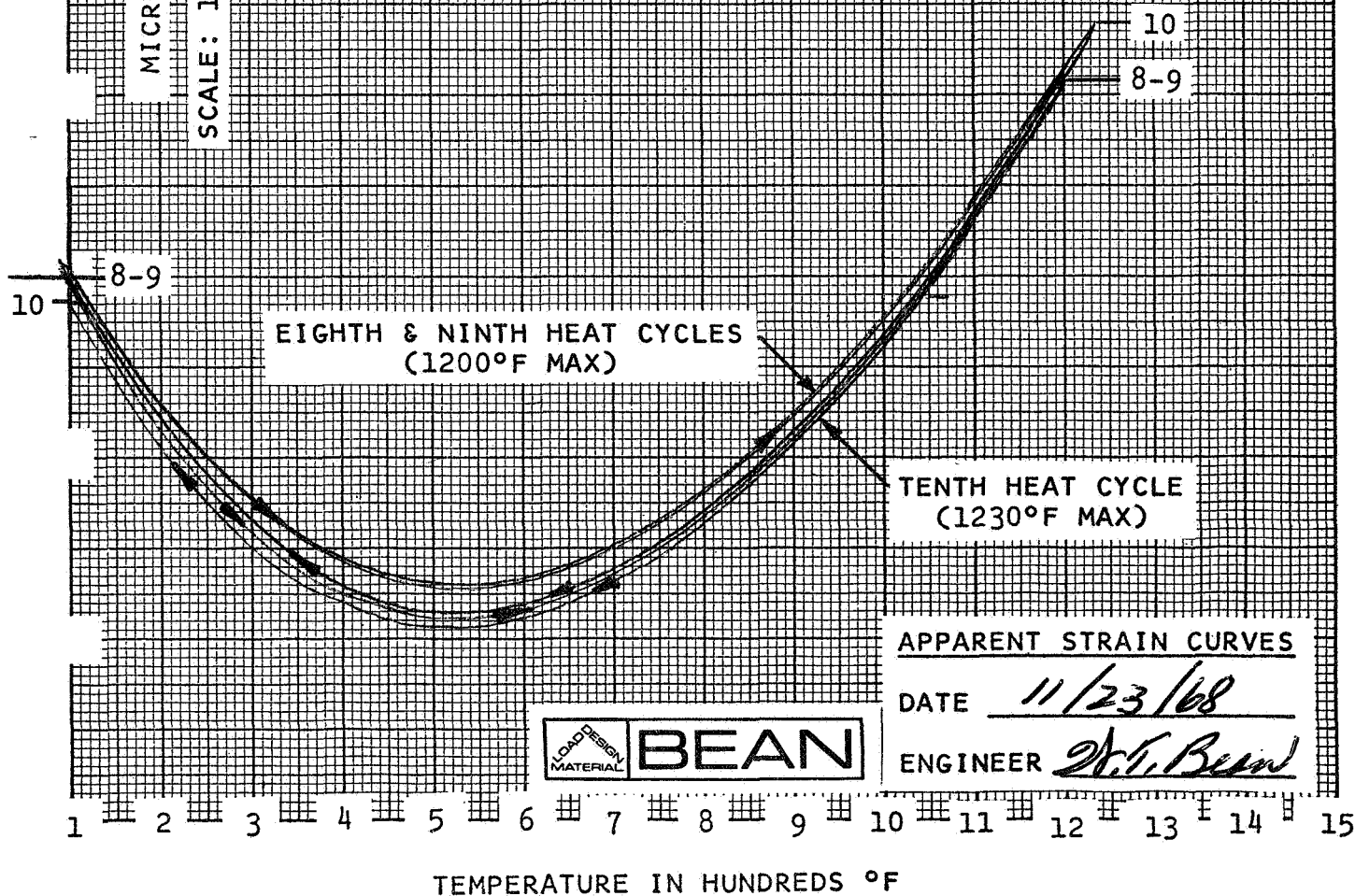
SAME SPECIMEN & GAGE AS RUN #141

LAPSED TIME @ 1200°F

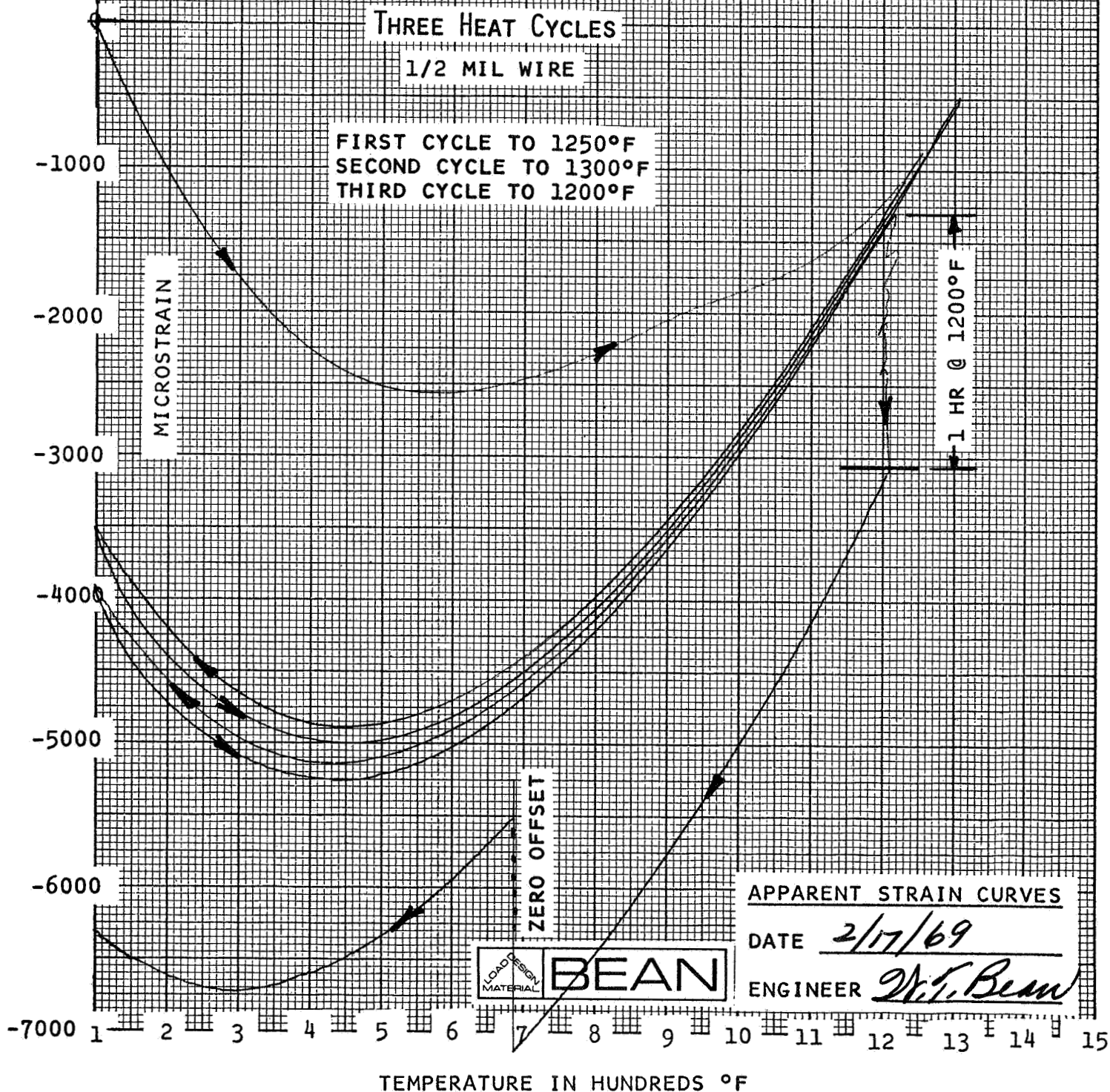
<u>CYCLE</u>	<u>HRS</u>
8	3
9	4
10	(1230°F)

MICROSTRAIN

SCALE: 1" = 1000µε



ALLOY #13/#3/40 RUN NO. 208  
ADHESIVE H-1 CURE 1 HR @ 600°F  
CLAMP PRESSURE No POST CURE No  
SPECIMEN MATERIAL HASTELLOY-X (1/16")  
HEATING & COOLING RATE 20/20 °F/MIN  
BRIDGE EXCITATION 6.4 DC VOLTS  
TEMPERATURE SENSOR C/A TC



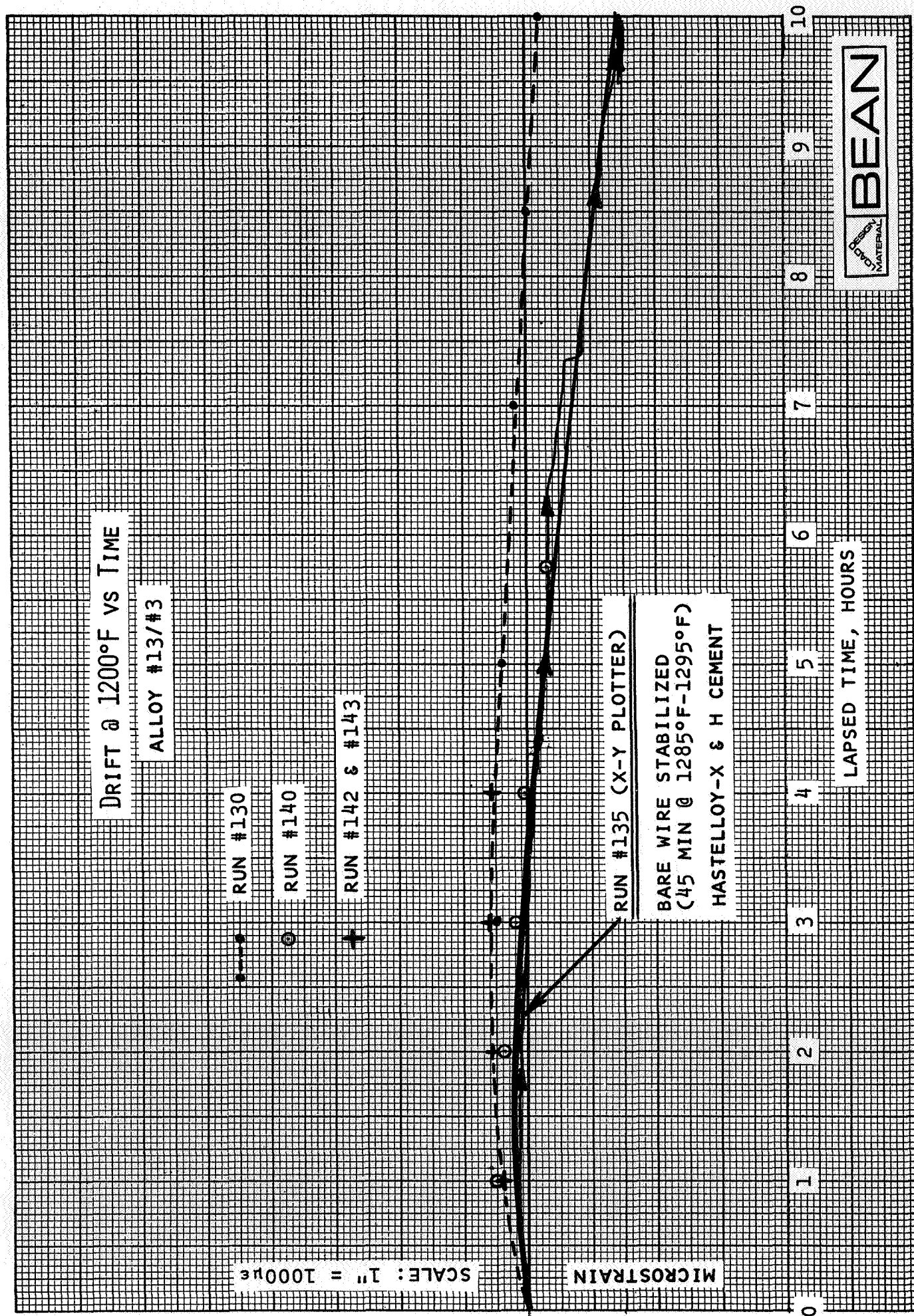


FIGURE 18.

### Gage Factor vs. Strain

Several gage factor vs. strain tests were conducted by mounting the Alloy #13/#3 gage on annealed aluminum bars (1/4" x 1" x 12").

Room temperature curing epoxies, heat curing epoxies, phenolics, and ceramic adhesives were employed. A constant-moment section for the strain gage was established by the loading fixture. An annealed constantan gage was mounted on the beam for comparative purposes.

The test results are shown in Figure 19. While the gage factor decreases with increasing strain as indicated, the captive filament will yield 100% gage factor on the recovery (relaxation) cycle and subsequent cycles.



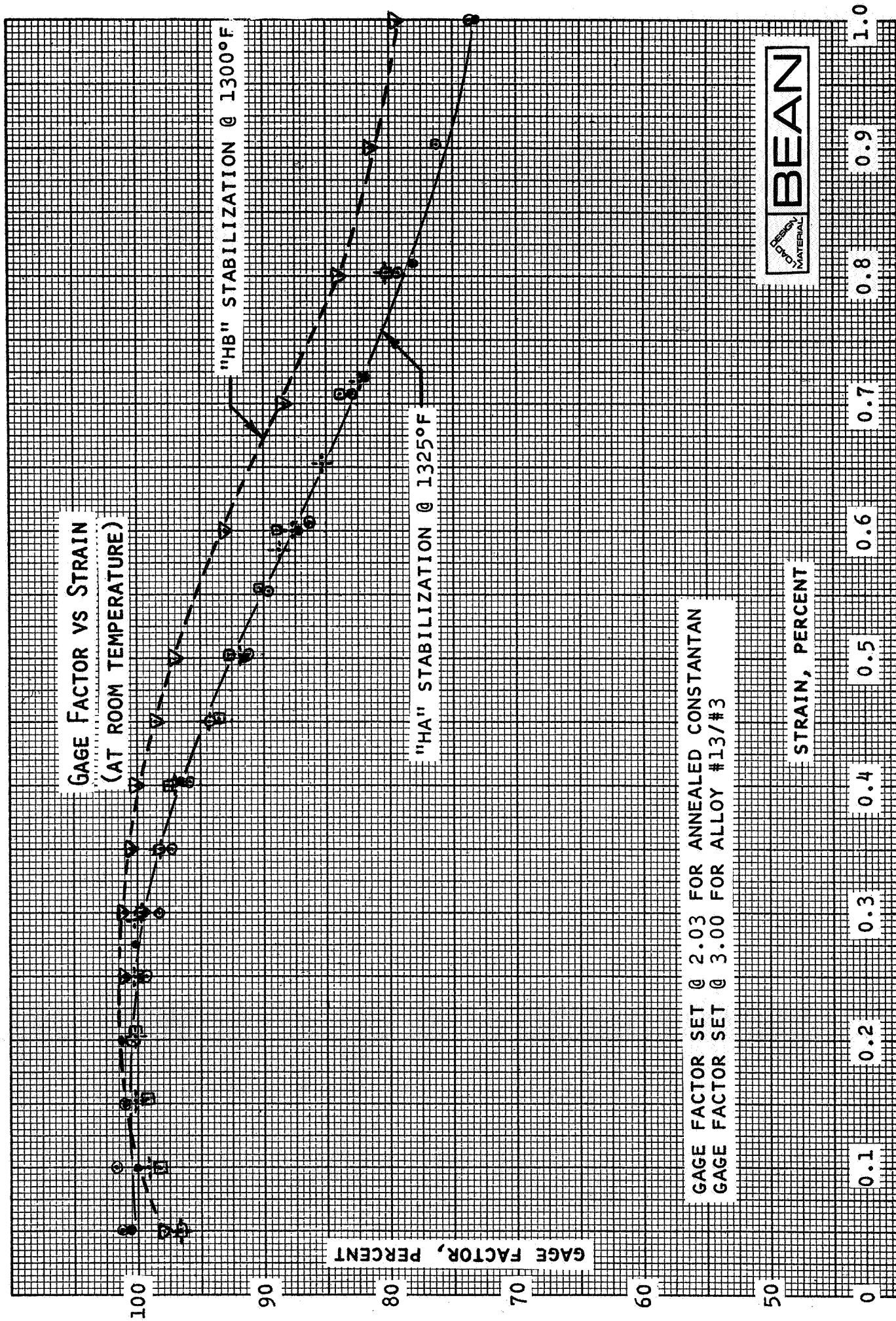


FIGURE 19.

## VII. CONCLUSIONS

All "Superalloys" tested contained significant amounts of nickel and chromium and exhibited solid solution phase changes below the 1200°F operating range. A change in the solid solution results in an anomaly of the resistance vs. temperature curve and yields an unsatisfactory alloy for high-temperature strain gage usage.

Alloy # 5, however, can be considered for high-temperature dynamic work and should result in a strain gage filament superior to those currently being used in the vibratory testing of turbine blades.

Alloy #13/#3 yields a strain gage that is suitable for the measurement of steady-state strains up to 1200°F and is feasible for commercial production.

Alloy # 3 is more stable at elevated temperature than Alloy # 13.

Alloy # 4 should be evaluated as a compensating filament.

## VIII. RECOMMENDATIONS

Alloys of platinum containing palladium-molybdenum should be investigated with a view toward:

1. Obtaining an improvement in the stability of the active filament (above 1000°F).
2. Achieving a more linear temperature coefficient of resistance. This will result in a more satisfactory apparent strain curve.
3. Increasing the coefficient of expansion in order to obtain better first cycle performance on high-expansion materials.
4. Reduction in gage factor. The judicious use of the proper compensating filament also would result in a more linear gage factor vs. strain.